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JOURNAL OF THE IRON AND STEEL INSTITUTE

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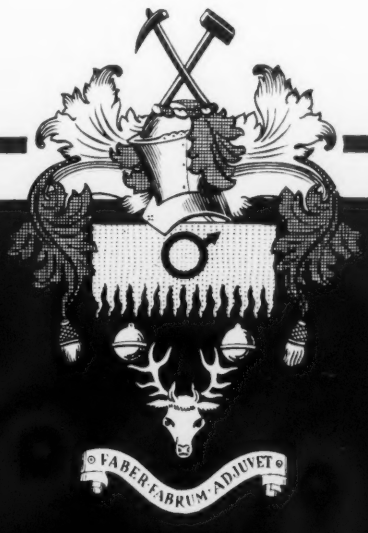

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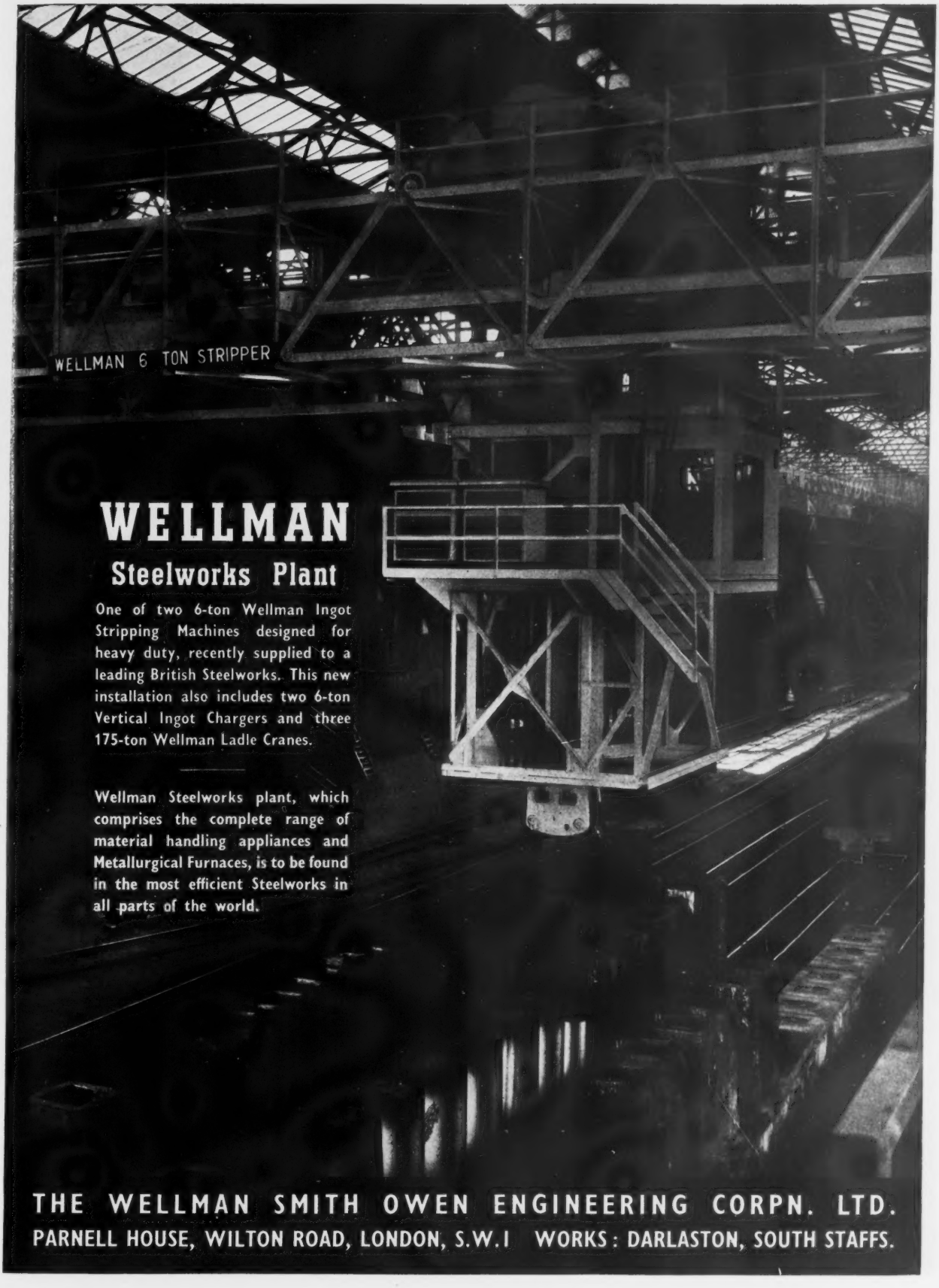

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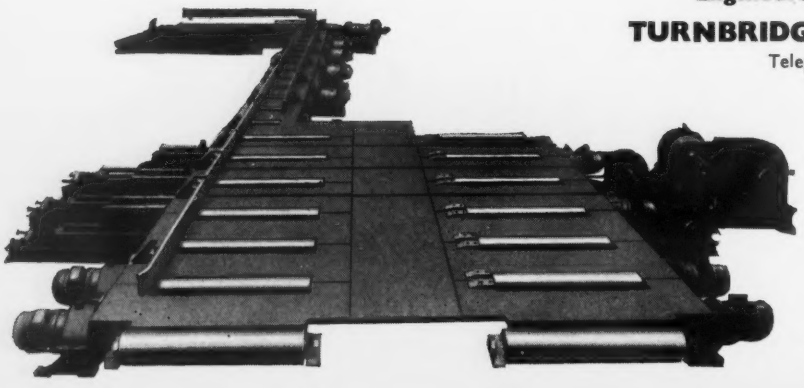

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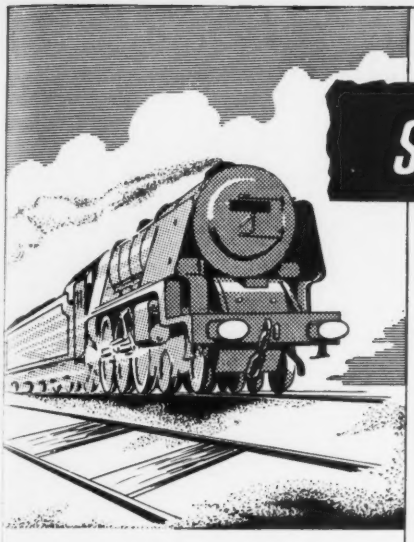

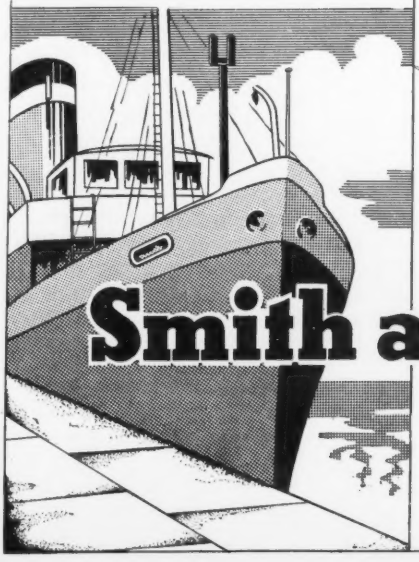

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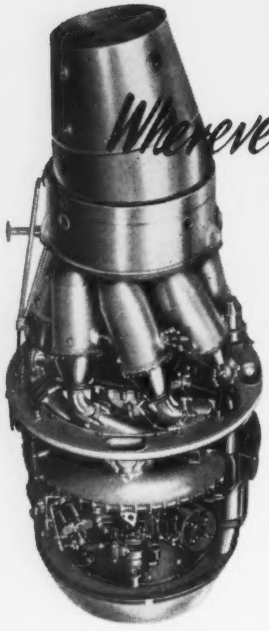

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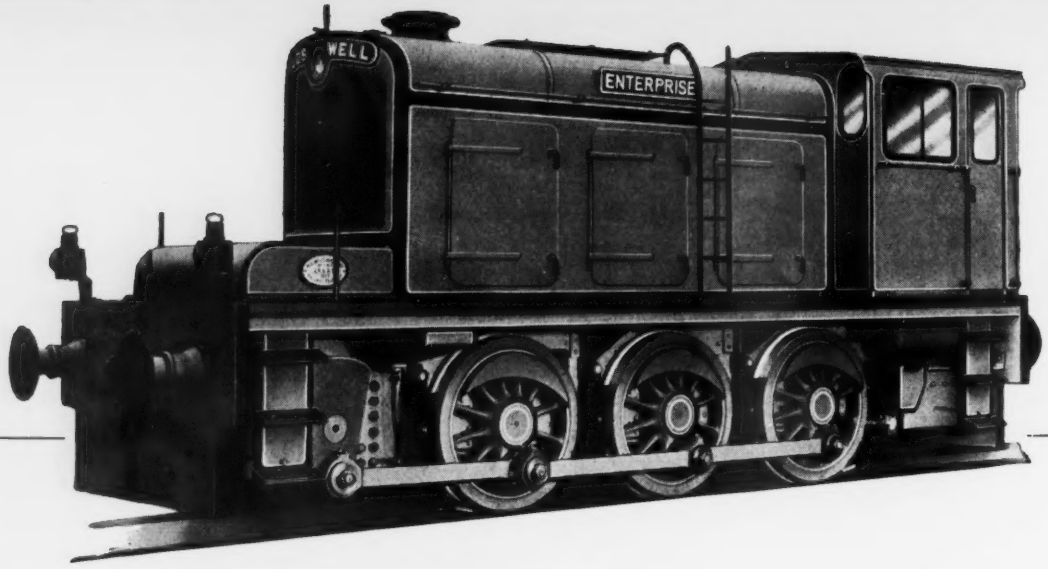

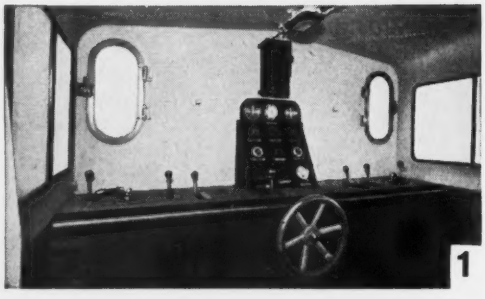
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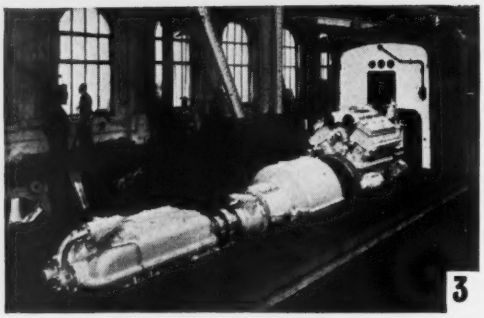
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2. *'Enterprise' at the head of a coal train*

3. *Installation in the locomotive 'Enterprise' showing left to right, the final reduction gearbox, the Dual Fluidrive transmission, and the Paxman V-6 pressure-charged constant h.p. engine.*

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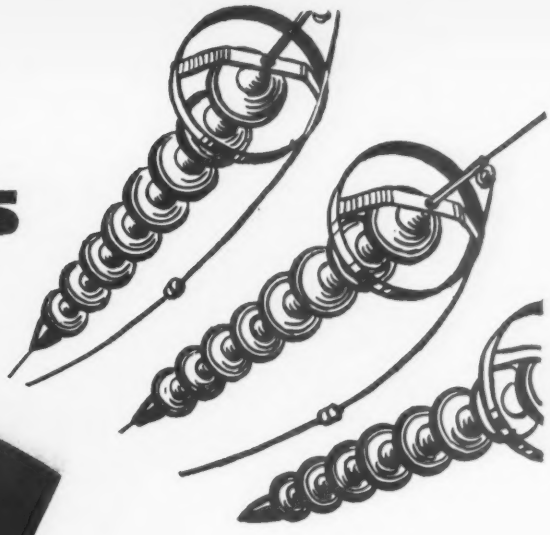

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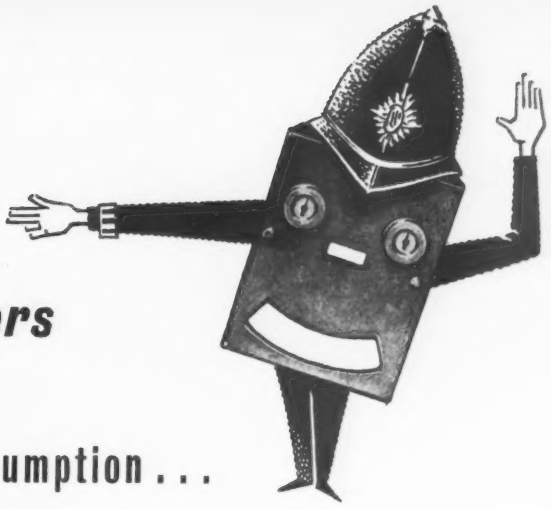

police your fuel consumption . . .

The Honeywell Furnace Pressure Controller installed on furnaces and boilers has achieved average fuel savings of 10 per cent . . . savings which often covered the instrument's cost within three months.
The instrument cuts waste by maintaining furnace pressure at its most economical level.

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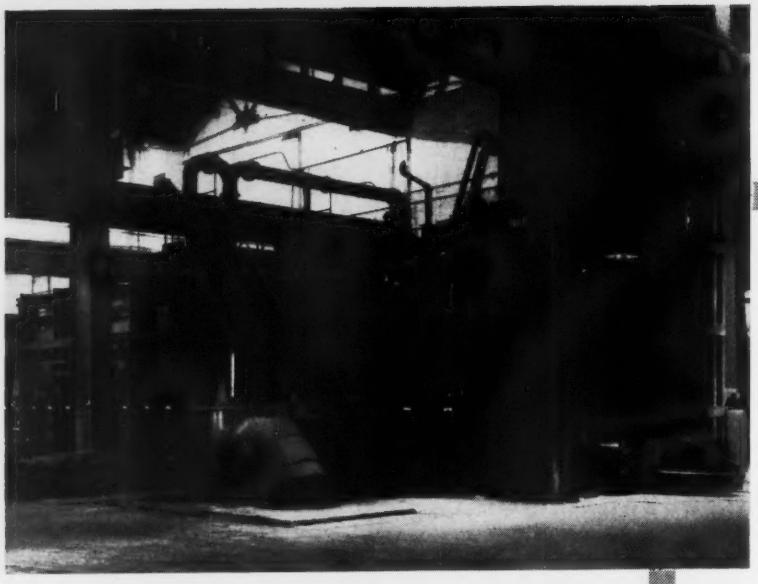

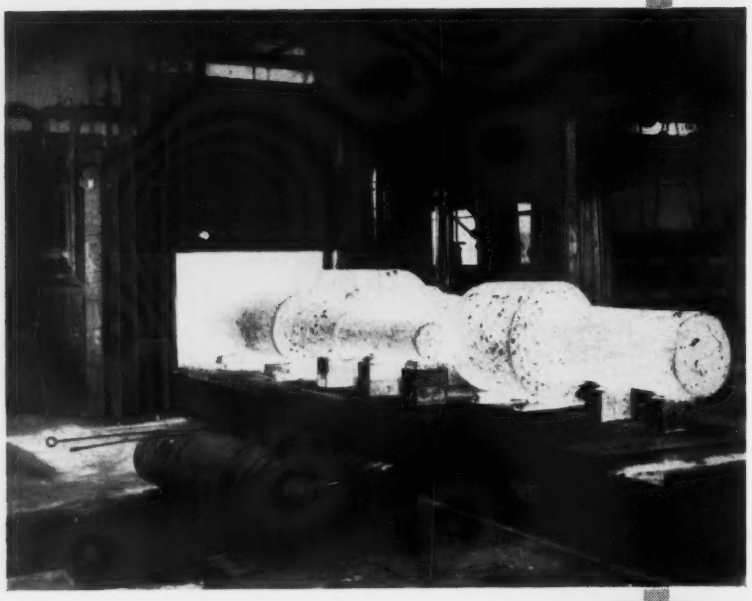

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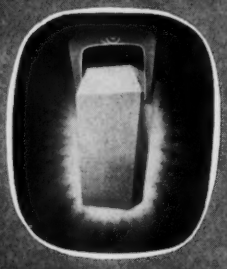

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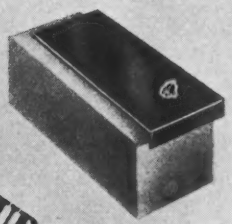

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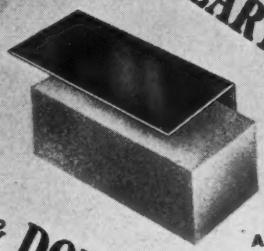

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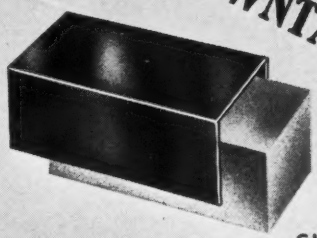

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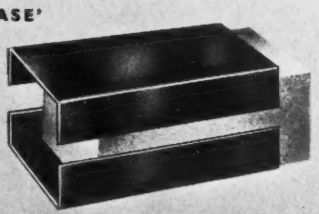

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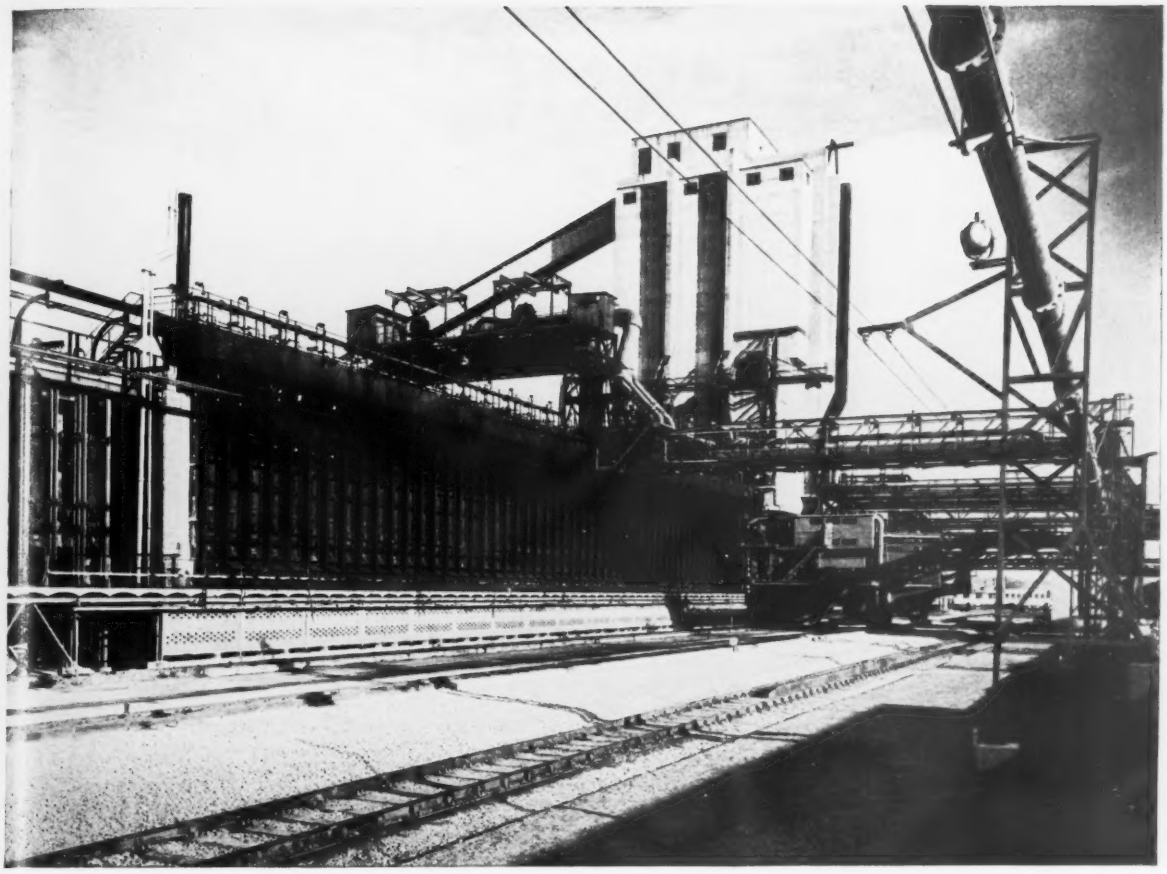

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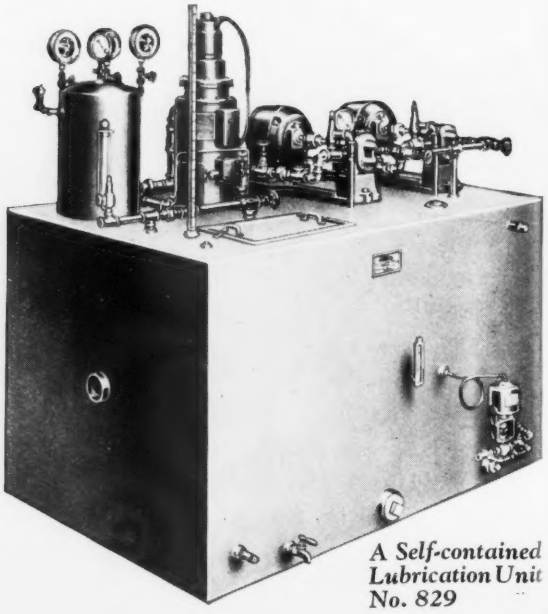

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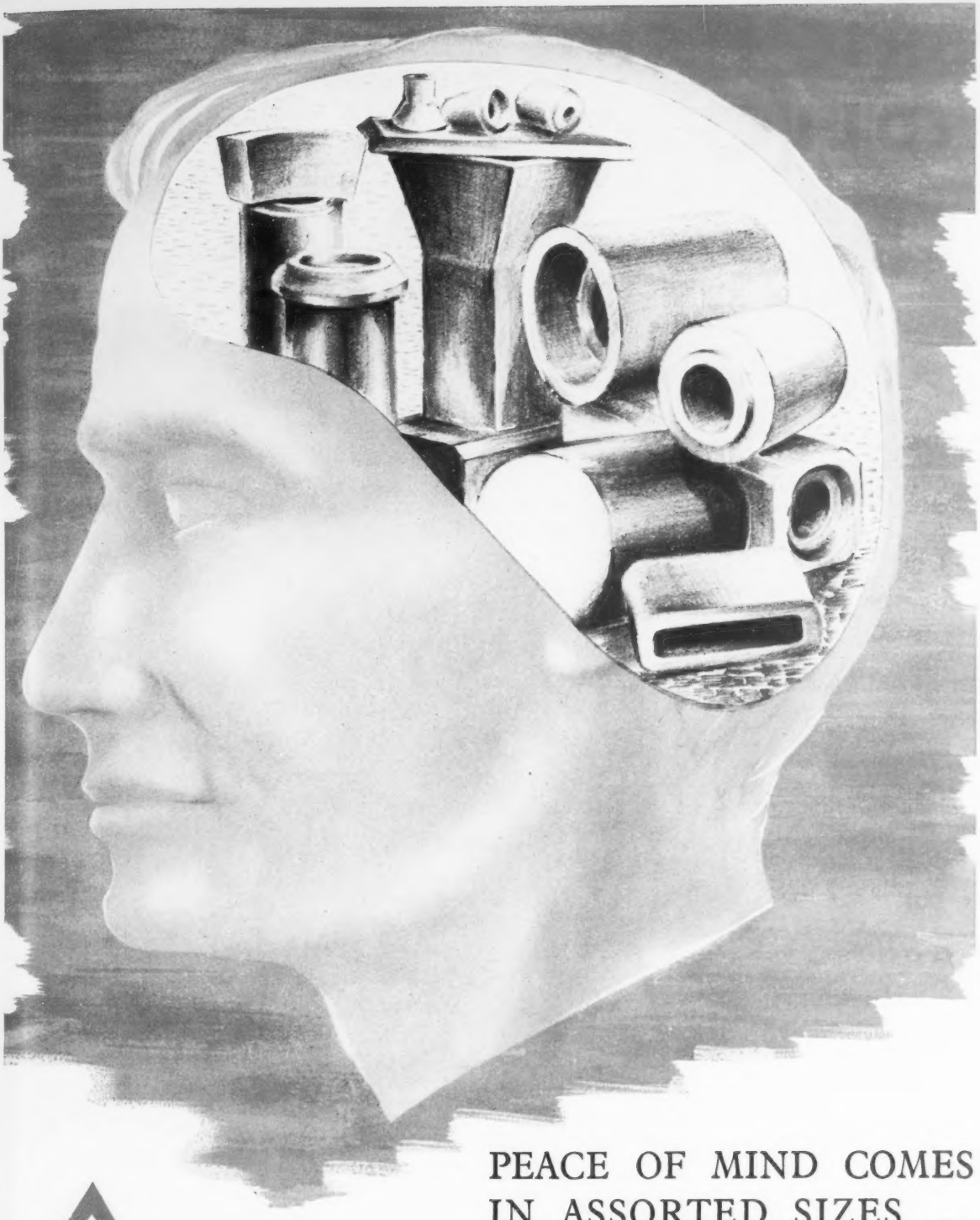

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Forgings and Castings up to 150 tons in Carbon and Alloy Steels, including Forged Steel Fully Hardened Work Rolls, Forged Steel Solid and Composite Back-up Rolls.

Illustration: Gear Wheel Rim Forging.

Finished Dimensions: Outside diameter 11′ 0¾″. Inside diameter 10′ 6½″. Width of forging 3′ 5″.

WILLIAM BEARDMORE & CO. LIMITED
Parkhead Steel Works, Glasgow, E.1
Also at 3 St. James's Square, London, S.W.1
and 2 St. John Street, Manchester, 3

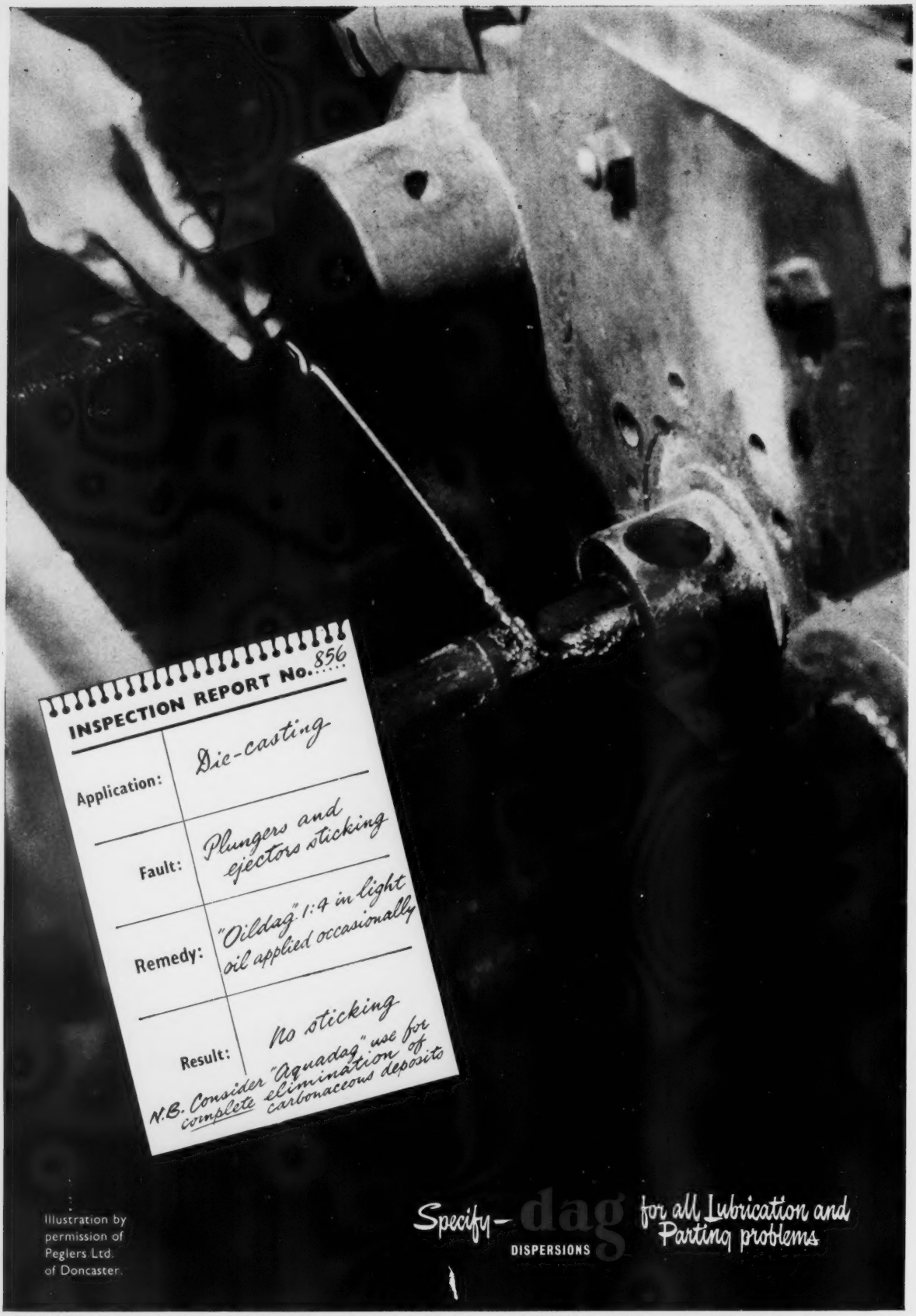
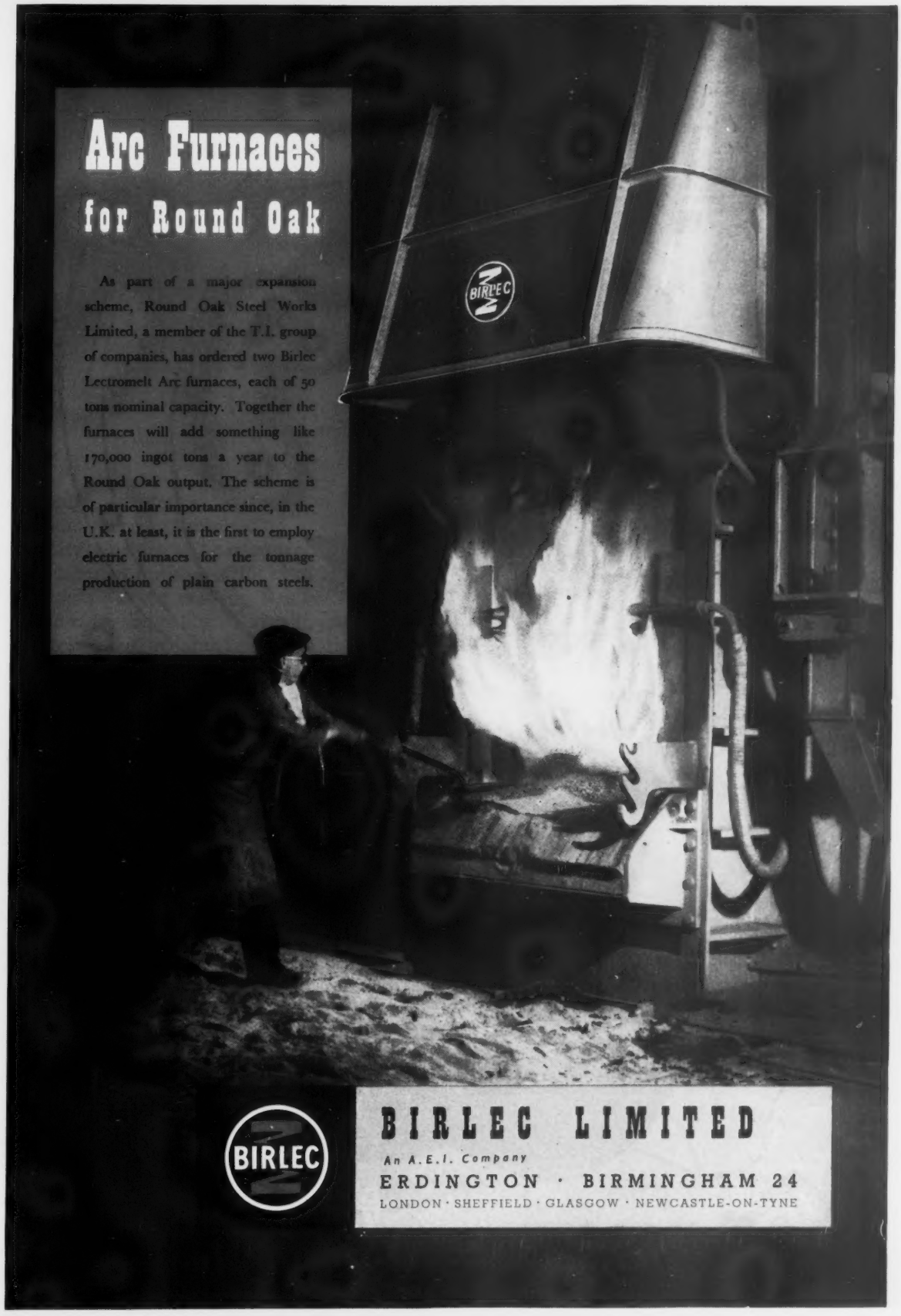

INSPECTION REPORT No. 856
Application: Die-casting
Fault: Plungers and ejectors sticking
Remedy: "Oildag" 1:4 in light oil applied occasionally
Result: No sticking
N.B. Consider "Aquadag" use for complete elimination of carbonaceous deposits
Specify- dag
DISPERSIONS
for all Lubrication and Parting problems

Illustration by permission of Peglers Ltd. of Doncaster.

ACHESON COLLOIDS LIMITED · 18 PALL MALL · LONDON SWI · TELEPHONE WHI 2034


Arc Furnaces
for Round Oak
As part of a major expansion scheme, Round Oak Steel Works Limited, a member of the T.I. group of companies, has ordered two Birlec Lectromelt Arc furnaces, each of 50 tons nominal capacity. Together the furnaces will add something like 170,000 ingot tons a year to the Round Oak output. The scheme is of particular importance since, in the U.K. at least, it is the first to employ electric furnaces for the tonnage production of plain carbon steels.
BIRLEC
BIRLEC LIMITED
An A.E.I. Company
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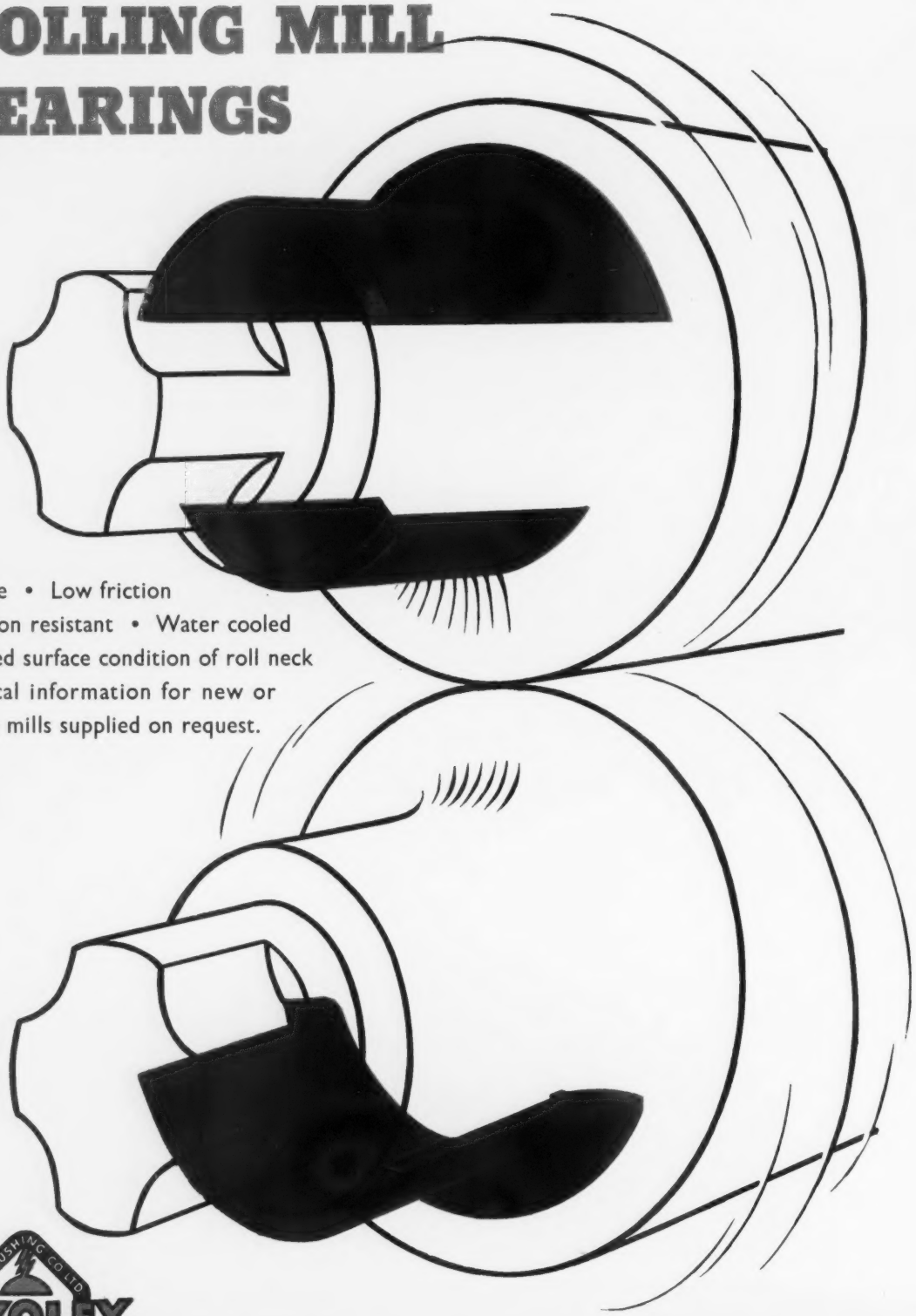
TEXOLEX

ROLLING MILL BEARINGS



Long life • Low friction
Corrosion resistant • Water cooled
Improved surface condition of roll neck
Technical information for new or existing mills supplied on request.

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Remarkable consistency in size and shape and absolute uniformity in texture and performance are the inherent features of Pickford Holland silica bricks. These exacting standards are maintained by the policy of installing the very latest plant and machinery, so that every process from quarry to finished brick, is regulated to the closest limits. Modern, fully instrumentated kilns (as illustrated) ensure even firing — an essential factor in the production of successful silica bricks. Up-to-date production methods in all departments are enabling Pickford Holland to keep pace with increasing demand for their refractories. More and more bricks for furnaces all over the world are being produced, and each and every brick conforms to the same high standards of manufacture

A modern kiln at the Crook, Co. Durham works of Pickford Holland

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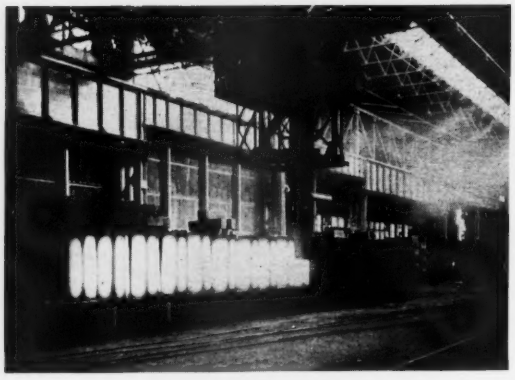


STRIPPING BAY

MORGAN MILL FLYING SHEARS

SIZES:

BLOOMS 5″ UP TO 9″

BILLETS 2″, 2¼″, 2½″, 3″, 3½″ & 4″

SLABS 5″ TO 16″ WIDE X 2″

SHEETBARS 12″ X ¼″ TO ¾″

ROD MILL SIZES

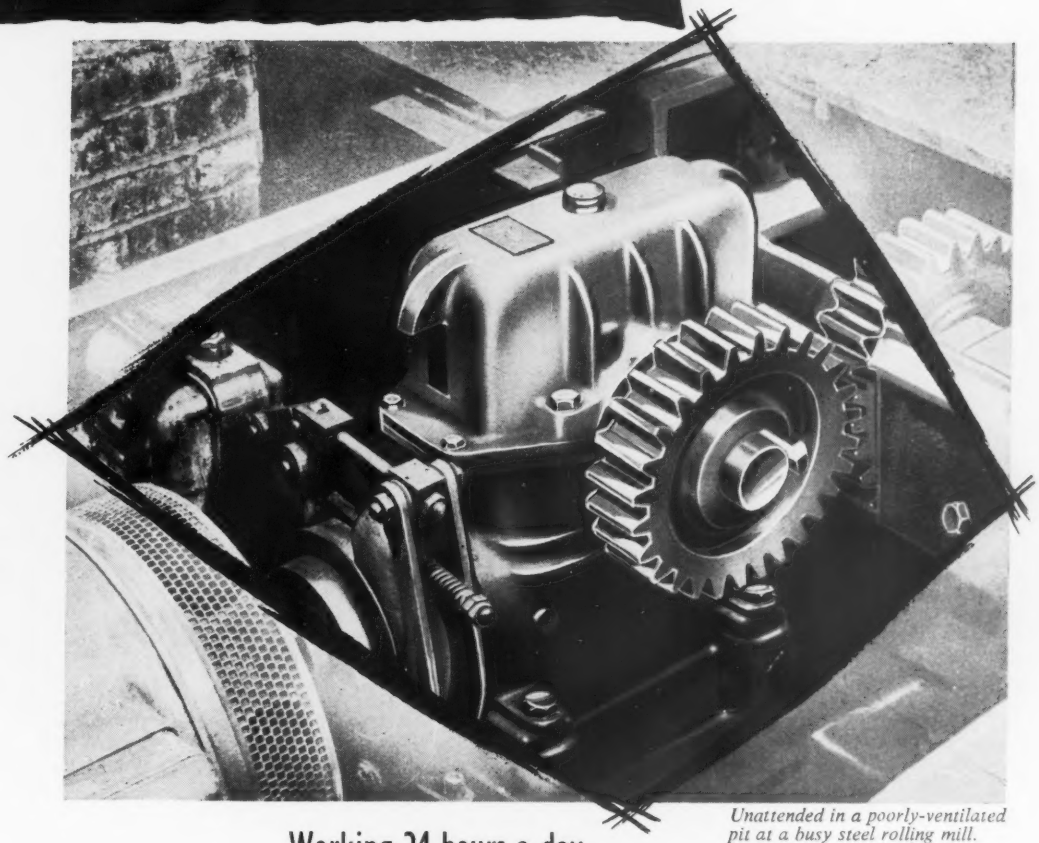
ROUNDS 5G. TO $\frac{9}{16}$″

SQUARES 6G. TO $\frac{7}{16}$″

RODS IN 500LB. COILS
(I/D 28″ O/D 36″)

ROD CONVEYOR

no trouble at all...



Unattended in a poorly-ventilated pit at a busy steel rolling mill.

Working 24 hours a day
to move 600 tons of hot steel a week
and averaging 130,000 stops and starts a month,
this Crofts Radiation Worm Reduction Gear
conveyor drive has done a vital production
job for over six and a half years.

And it goes on and on and on with no trouble at all, the only attention being maintenance of the correct oil level.

You can get first class gears like this
from stock for powers up to **140 hp,**
ratios up to 60 to 1 and $1\frac{1}{8}''$ to 9″ centres

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The standard range covers powers up to 450 hp—ask for Publication 521/A

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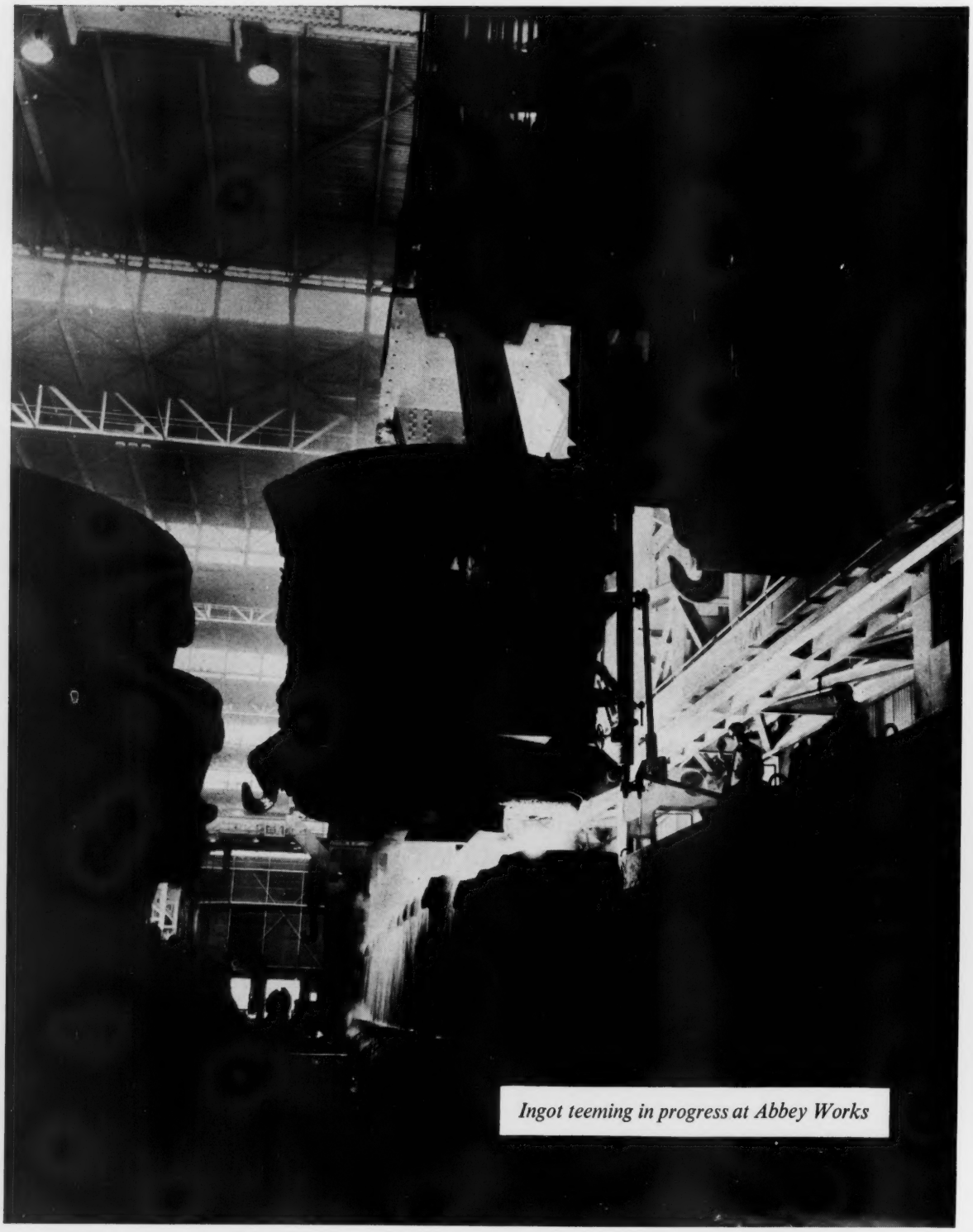
One-third of Britain's SHEET STEEL

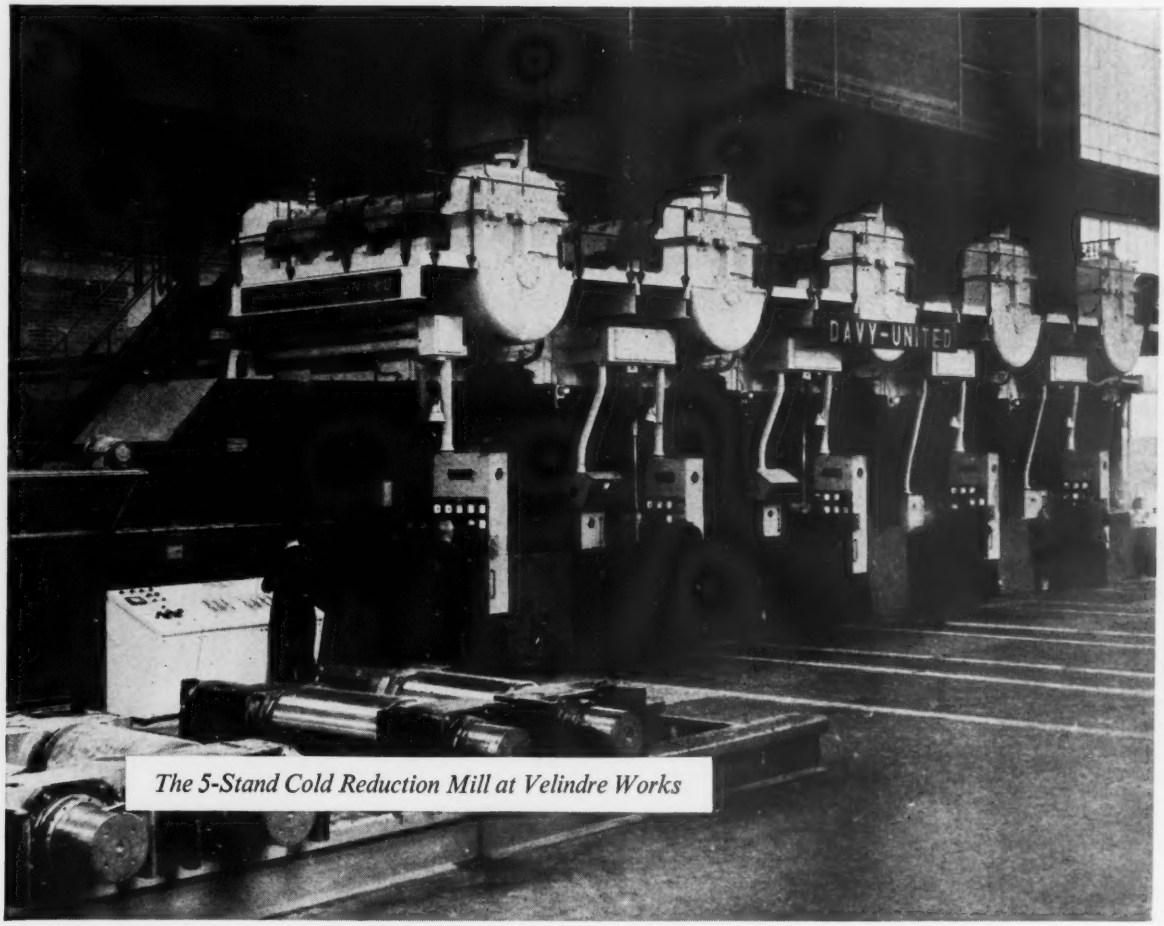


Ingot teeming in progress at Abbey Works

ENQUIRIES for Sheet and Plate products to: The Sales Manager, Abbey Works, Port Talbot, Glamorgan

. . . two-thirds of Britain's TINPLATE are made by

THE STEEL COMPANY OF WALES LIMITED



The 5-Stand Cold Reduction Mill at Velindre Works

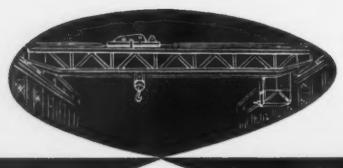
ENQUIRIES for Tinplate and Blackplate products to: The Sales Manager, Carmarthen Road, Swansea, Glamorgan

JOSEPH ADAMSON

Electric Overhead Travelling Cranes

JAC

All Joseph Adamson electric overhead travelling cranes are built to give unfailing service under the most exacting conditions. Generous proportions, provision for easy maintenance and the special attention given to operator control and safety measures are features of Joseph Adamson cranes. Electric overhead travelling cranes can be supplied to all specifications, including cranes suited to the most exacting 24 hours-a-day process work.



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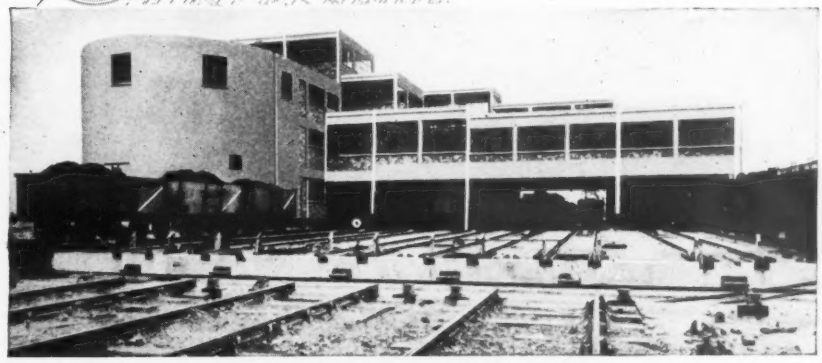
Erected at Dalkeith to treat run-of-mine coal from eight producing units in the vicinity. The Coal Preparation Plant, which is capable of handling 400 tons of coal per hour, embodies hand picking of large coal, Baum washing, and flocculation of slurry.



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Write for complete technical specification of our standard 18 – 130 h.p. range for duties from 60 – 950 g.p.m. against 50 – 1000 feet head. Deliveries can be arranged to meet all urgent requirements. We also invite your enquiries for our large Submersible pumping units.

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FORCED - CIRCULATION BOILER PLANT

will be built at the Margam steelworks of the Steel Company of Wales. This plant, the first of its type in this country, will generate 240,000 lb of steam per hour at 3300 lb per sq inch and 1060°F, with re-heat to 840°F, the most advanced steam conditions ever commercially used in Britain. For steam generation at pressures near, at and above the critical pressure the Benson 'Once Through' forced-circulation boiler offers outstanding advantages in flexibility of operation and in speed and economy of construction and maintenance. It is particularly suitable for re-heat steam cycles and is well adapted to two-shift operation. Simon-Carves will be glad to discuss projects and designs with users of steam power at home and overseas.

Steam power plant by Simon-Carves Ltd

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Super Grade Low Alumina
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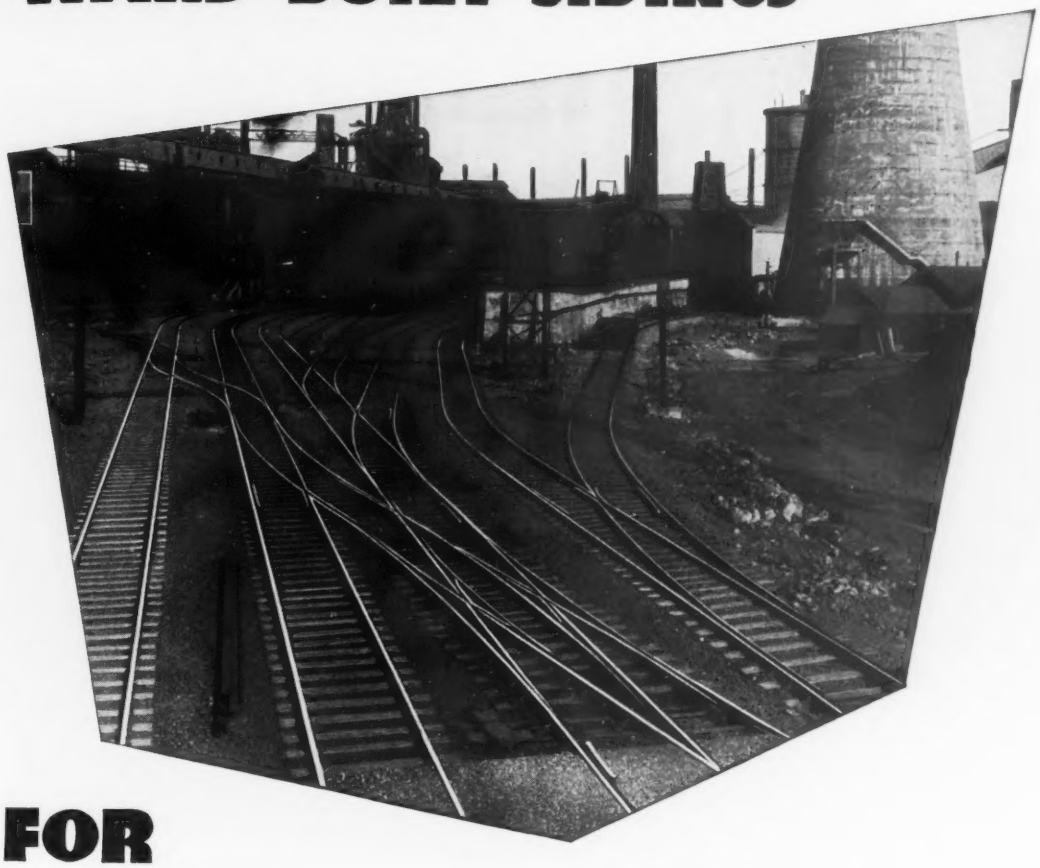

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Wards bring just the same skill and experience to the simplest run-in as they do to the construction of larger industrial installations for iron and steel works. Earth-moving, site clearance and the planning, construction and maintenance of sidings – all are part of the Ward service to Industry.

Illustration shows Ward-built sidings for Dorman Long & Co. Ltd.

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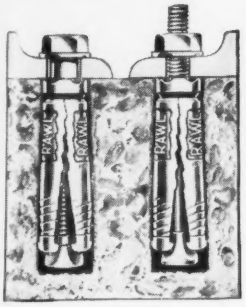
RAWLBOLTS

There is no waiting for cement to harden when you use Rawlbolts. The holes are drilled with a Rawltool to the exact size, the Rawlbolts dropped in and after the machine has been positioned the bolts are tightened. The expansion of the members locks the bolts in the holes. They cannot work loose through vibration or shock. The machine can be put into operation immediately.

Rawlbolts have earned a sterling reputation for strength and reliability throughout the world—they are used by the million every month. Rawlbolts grip by *expansion*—their strength as a fixing is based on the enormous compressive strength of concrete itself.

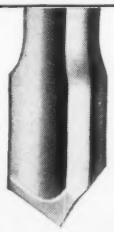


RAWLBOLTS ARE MADE IN TWO TYPES

For fixing heavy machinery to floors there is the Loose Bolt type of Rawlbolt which enables the machine to be slid into position after the Rawlbolt has been inserted. For wall fixings use the Bolt Projecting type which will position the fixing before tightening up.

Please write for Chart and descriptive literature.

Tools that save time For hole boring there is a big range of high efficiency Rawlplug tools for use by hand, electric and air power.



RAWLDRILLS

For hand boring for Rawlbolt sizes A to G.

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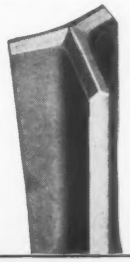
For hand boring for all Rawlbolt sizes.

DURIUM MASONRY DRILLS

For use in hand and electric drills for Rawlbolt sizes C to G.

TRIFORM DRILLS

For use in electric hammers for Rawlbolts sizes C to K.



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For use in electric hammers for Rawlbolt sizes C to J.

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For use in pneumatic hammers for Rawlbolt sizes E to K.

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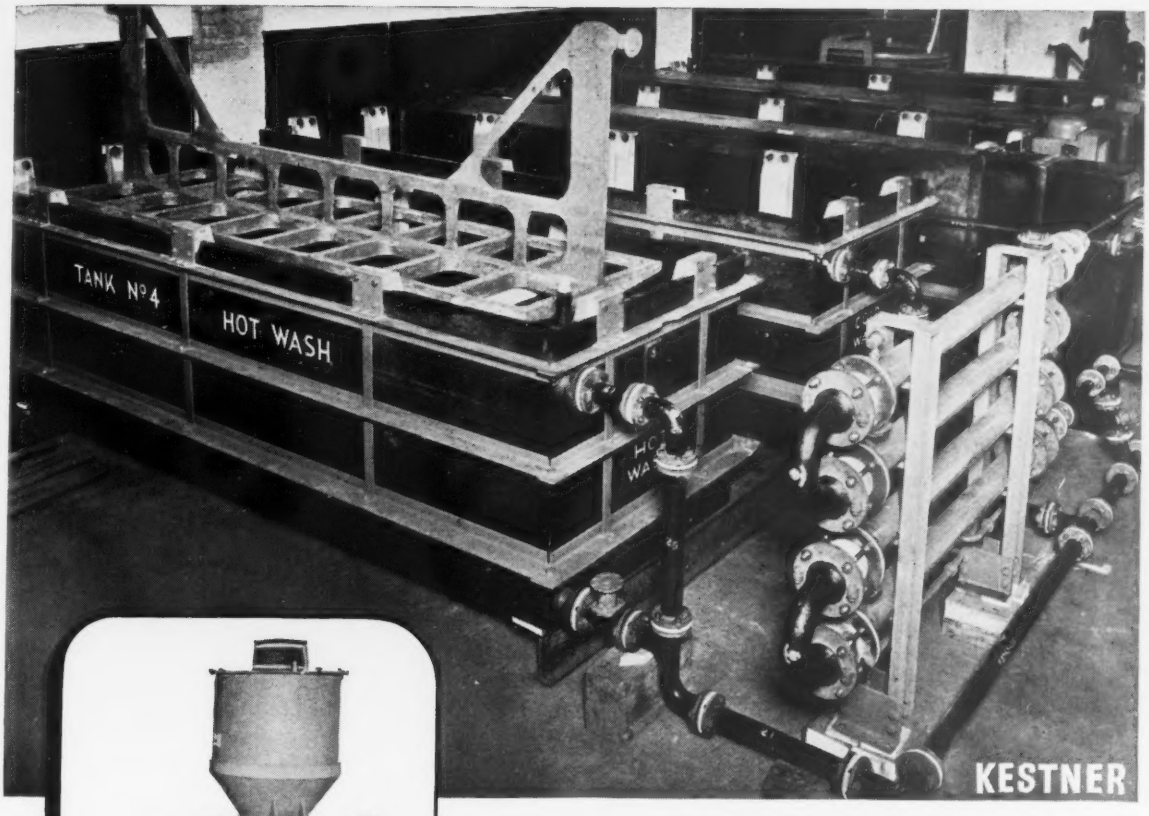

FOR COPPER SHEET

with recovery of copper from spent pickle liquor

The Kestner organisation has over 20 years' experience in pickling processes for all industries, and thus is well fitted to advise you on your problems. We specialise in effluent disposal and acid recovery. The illustrations show a complete plant for copper pickling incorporating the Kestner Patent Copper/Acid Recovery System.

KESTNER PATENT NEUTRALISER

Used for wash waters and in other instances where it is not economic to recover acid but disposal problems must be solved.

Kestner THE CHEMICAL ENGINEERS

KEEBUSH CONSTRUCTIONAL MATERIAL

KEEBUSH is used extensively in this as in other plants handling corrosive liquors. Full details will be sent at your request.

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Brosius manipulator and manipulet

150 Brosius Manipulators now in use throughout the world carry out all the manipulation necessary during forging, saving manpower and time.

The smallest Manipulator will handle pieces up to 2,000 lbs. in weight. A wide range of designs are available, the maximum being suitable for pieces up to 20,000 lbs. in weight.

Manipulets will handle up to 500 lbs. or 1,500 lbs.

THE MANIPULET

THE HEAD WRIGHTSON MACHINE COMPANY LTD

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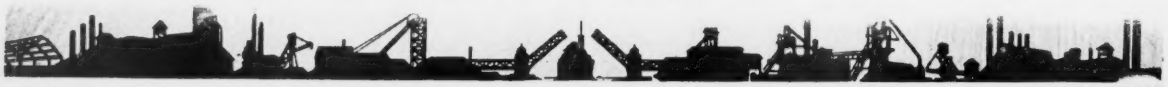

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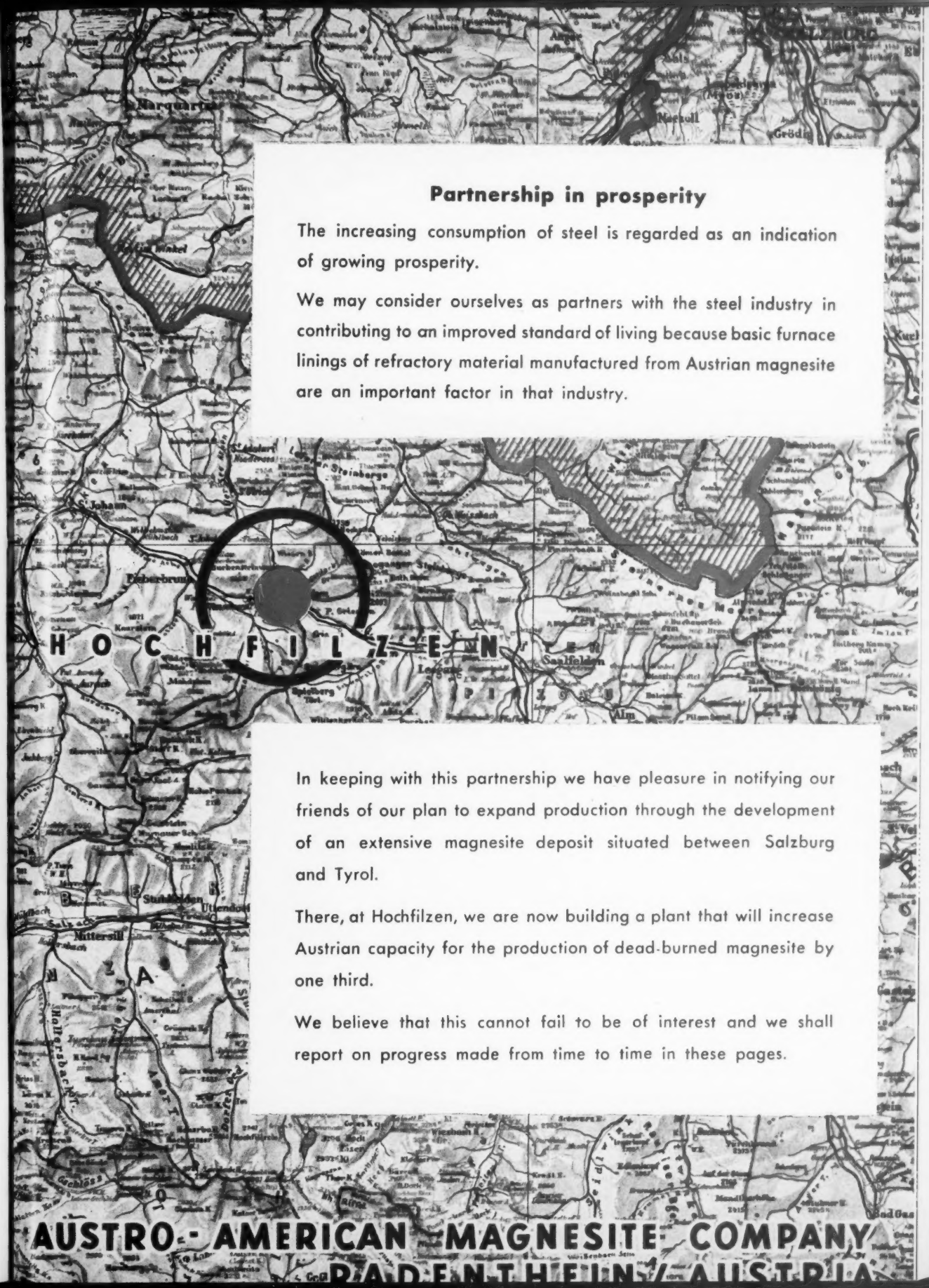


Partnership in prosperity

The increasing consumption of steel is regarded as an indication of growing prosperity.

We may consider ourselves as partners with the steel industry in contributing to an improved standard of living because basic furnace linings of refractory material manufactured from Austrian magnesite are an important factor in that industry.

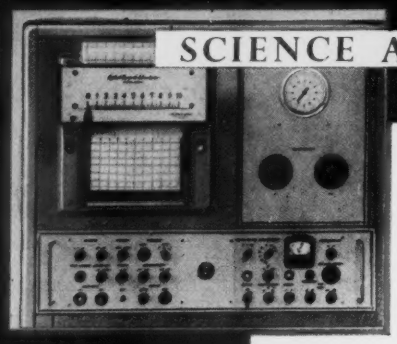
In keeping with this partnership we have pleasure in notifying our friends of our plan to expand production through the development of an extensive magnesite deposit situated between Salzburg and Tyrol.

There, at Hochfilzen, we are now building a plant that will increase Austrian capacity for the production of dead-burned magnesite by one third.

We believe that this cannot fail to be of interest and we shall report on progress made from time to time in these pages.

AUSTRO-AMERICAN MAGNESITE COMPANY
RADENTHEIN/AUSTRIA

SCIENCE AND THE STEEL TUBE AGE : 2



QUANTOMETER

In the great, modern steel and tube works of Stewarts and Lloyds at Corby the daily production of 2,700 tons of steel calls for rapid and accurate analysis of samples.

Chemical analysis has to some extent been replaced by the photographic spectrograph but to meet the need for still greater speed there is now in use at Corby an automatic direct-reading spectrographic analyser known as a Quantometer.

A small sample of steel, taken during a melt, is dispatched to the laboratory by pneumatic conveyor and an electric spark is struck between the sample and a counter electrode. The light from the spark is focused upon a special diffraction grating which produces an extended spectrum. The significant spectral lines fall on photomultipliers which measure their density. A quantitative assessment of the amount of each element is then recorded upon a chart (visible in the small illustration). The whole operation takes less than two minutes and this system provides a constant and rapid check on the quality of the steel.

STEWARTS AND LLOYDS
LIMITED
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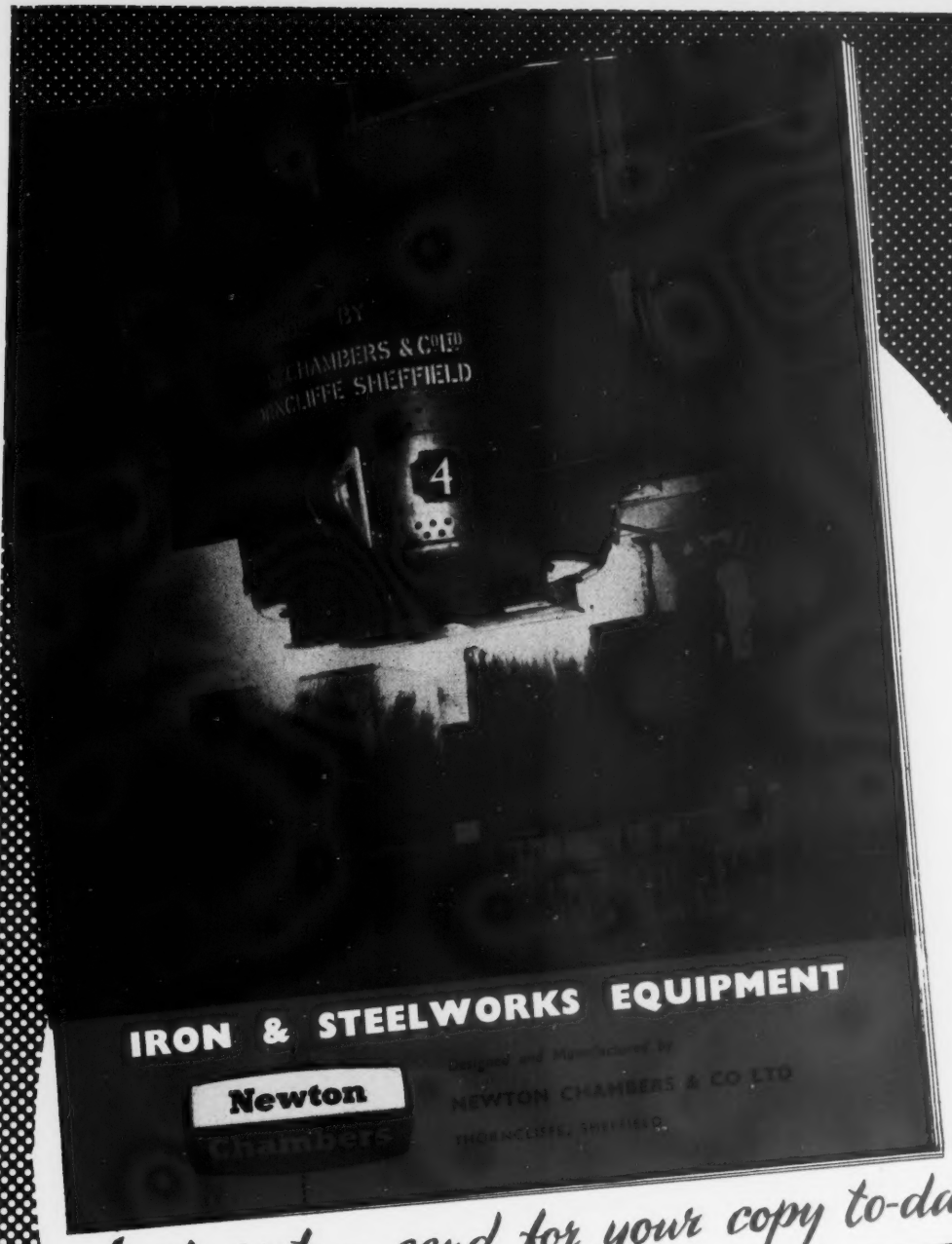

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To:- **NEWTON CHAMBERS & CO. LTD.**
(ENGINEERING DIVISION)
THORNCLIFFE **NR. SHEFFIELD**

I should be pleased if you would kindly forward a copy of your new brochure describing Iron and Steel Works equipment.

Name: .....

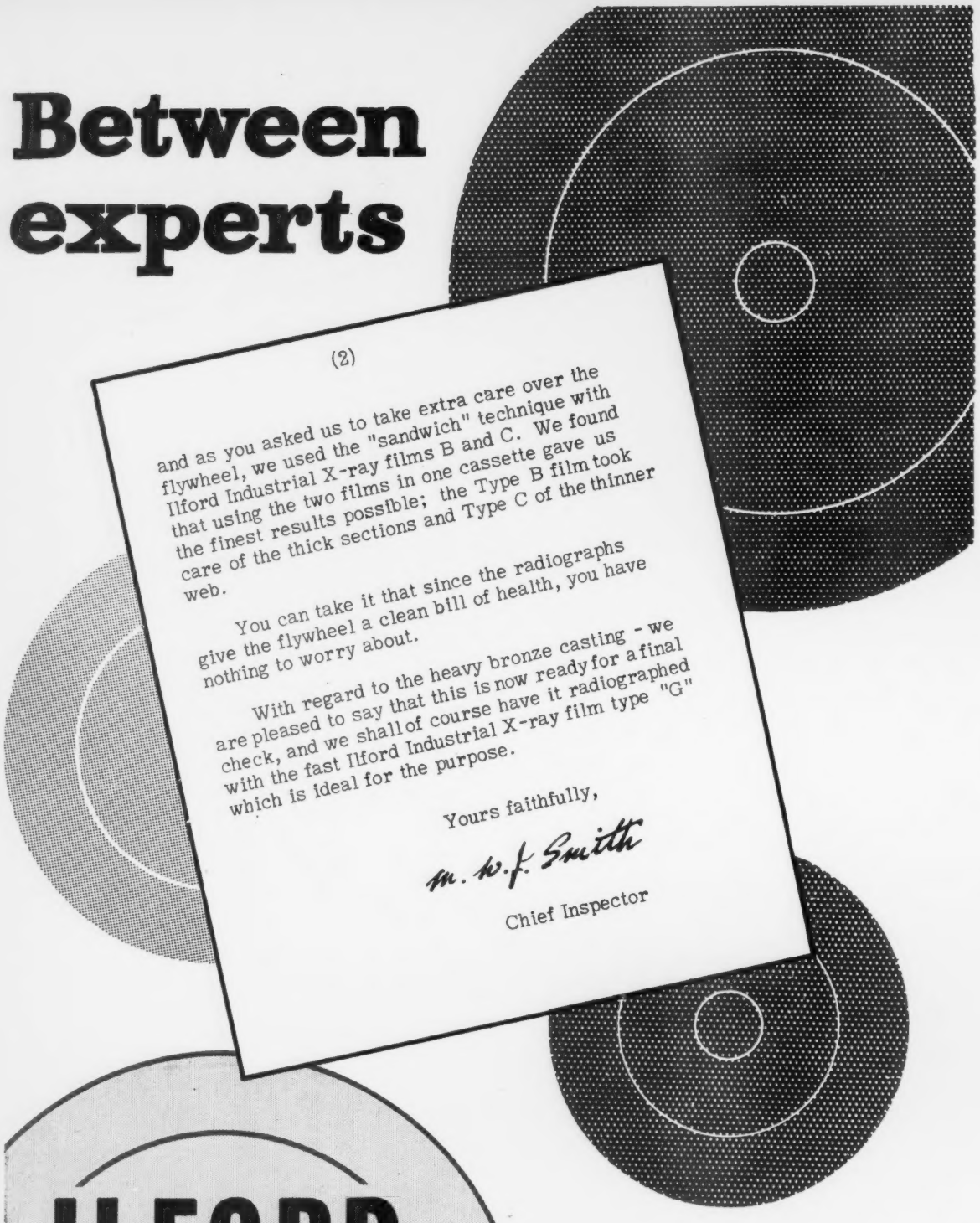
Status: .....

Firm: .....

Address: .....

N.C.11

Between experts


(2)
and as you asked us to take extra care over the flywheel, we used the "sandwich" technique with Ilford Industrial X-ray films B and C. We found that using the two films in one cassette gave us the finest results possible; the Type B film took care of the thick sections and Type C of the thinner web.
You can take it that since the radiographs give the flywheel a clean bill of health, you have nothing to worry about.
With regard to the heavy bronze casting - we are pleased to say that this is now ready for a final check, and we shall of course have it radiographed with the fast Ilford Industrial X-ray film type "G" which is ideal for the purpose.
Yours faithfully,
m. w. f. Smith
Chief Inspector

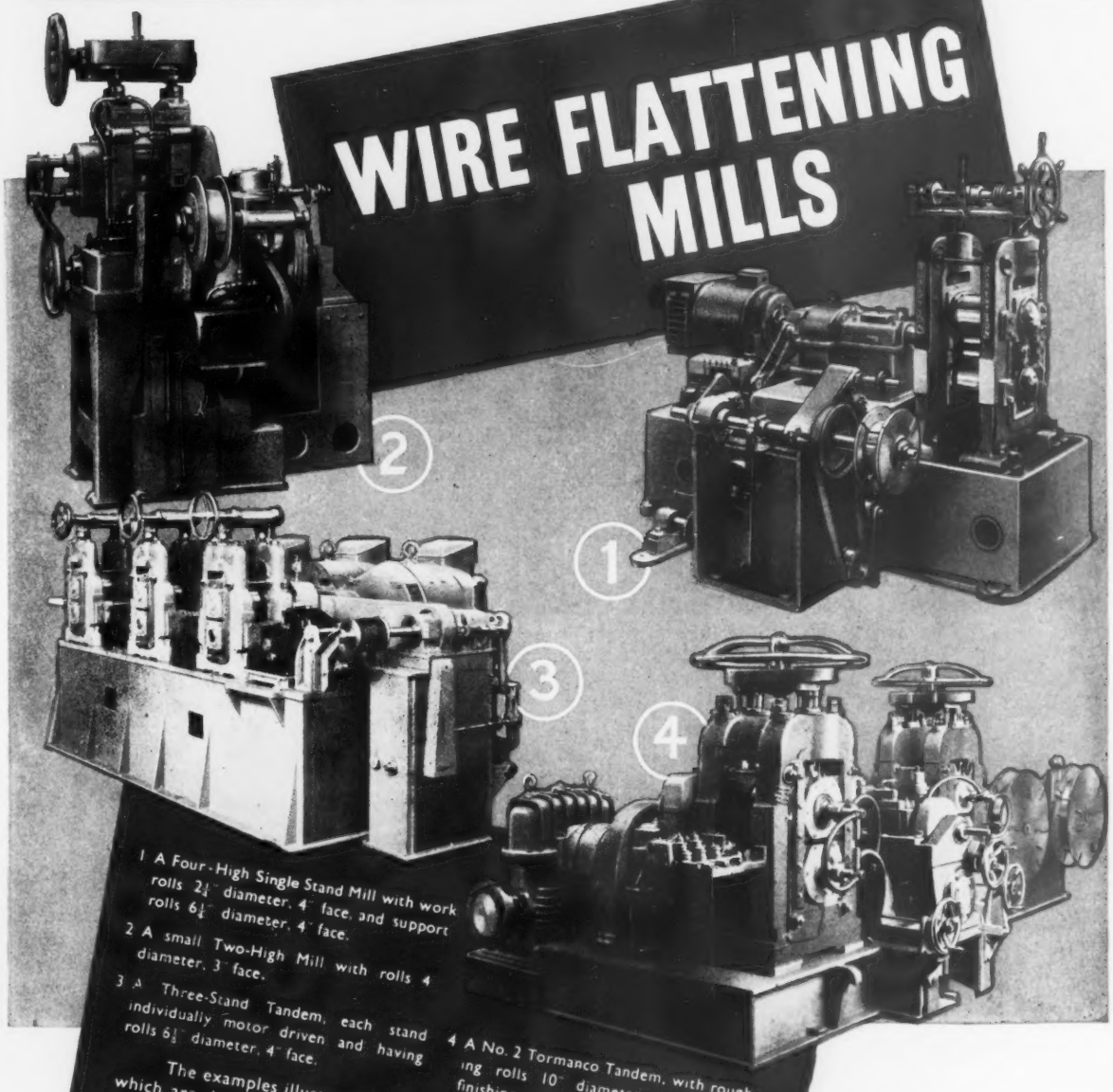
ILFORD **X-RAY FILMS**

FOR INDUSTRIAL RADIOGRAPHY

ILFORD LIMITED · ILFORD · LONDON

ROBERTSON

WIRE FLATTENING MILLS



1 A Four-High Single Stand Mill with work rolls 2¼" diameter, 4" face, and support rolls 6¼" diameter, 4" face.

2 A small Two-High Mill with rolls 4" diameter, 3" face.

3 A Three-Stand Tandem, each stand individually motor driven and having rolls 6½" diameter, 4" face.

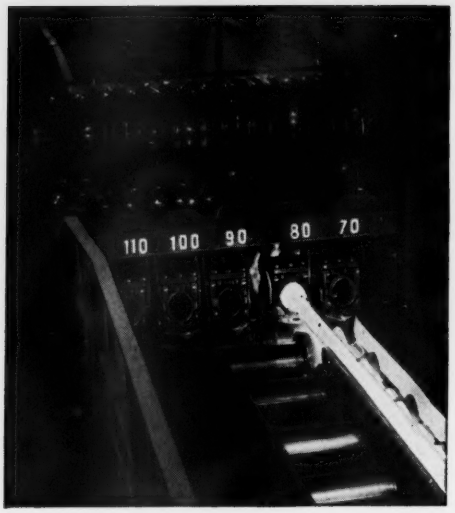
4 A No. 2 Tormanco Tandem, with roughing rolls 10" diameter, 6" face, and finishing rolls 8" diameter, 6" face.

The examples illustrated above are from the range of Robertson Mills, which are designed for the production of square, rectangular or flat strip from round rod and wire in steel and all non-ferrous metals and alloys.

W. H. A. ROBERTSON & CO. LTD., BEDFORD, ENGLAND

LICENSEES FOR THE BUILDING OF SENDZIMIR COLD REDUCTION MILLS & PLANETARY HOT MILLS

8 good reasons why you should use these ROLLER GUIDES in your bar or wire rod mill



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1 The entry friction guides are rigidly clamped into the guide box. They are intended to lead the oval to the groove in the roller, to protect the rollers against overloading, and to straighten bent rods.
The groove in the entry guides is made about 1/8" wider than the oval.

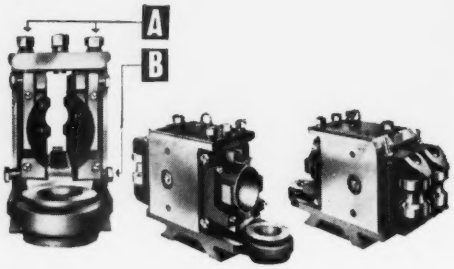
2 The rollers are mounted on leaf springs, which can be adjusted by means of the screws "B", and hold the oval steadily even if there should be some slight variation in the thickness of the oval.

3 If the thickness of the oval should vary, the springs of both rollers yield an equal amount, so that the oval remains in the centre of the groove.

4 To tilt the oval, the screws "A" are adjusted. One roller will then be lifted as much as the other is lowered.

5 As the oval is held very rigidly, the leader oval for wire rod may be thick, unless other circumstances call for a thinner oval.

6 The roller guide assemblies are narrow, and all screws that require adjustment during rolling are accessible from the front of the mill. No lateral space outside the guide box is therefore required for gaining access to the set screws, and the guide box assembly can thus be located close to the mill housing.



7 As the groove in the entry guides is wide and nothing but rolling friction acts on the oval, the latter is very easily introduced into the pass, and there is practically no risk of scratching the bar.

8 The roller guide may be used not only for leader and drawing oval passes but also for edging flats as well as for rolling squares, hexagons, octagons and various other sections, for instance in reduction passes for hexagon. It is suitable for all types of rolling mill. An important advantage is that the roller guide enables repeaters to be used in rolling plump leader-ovals.

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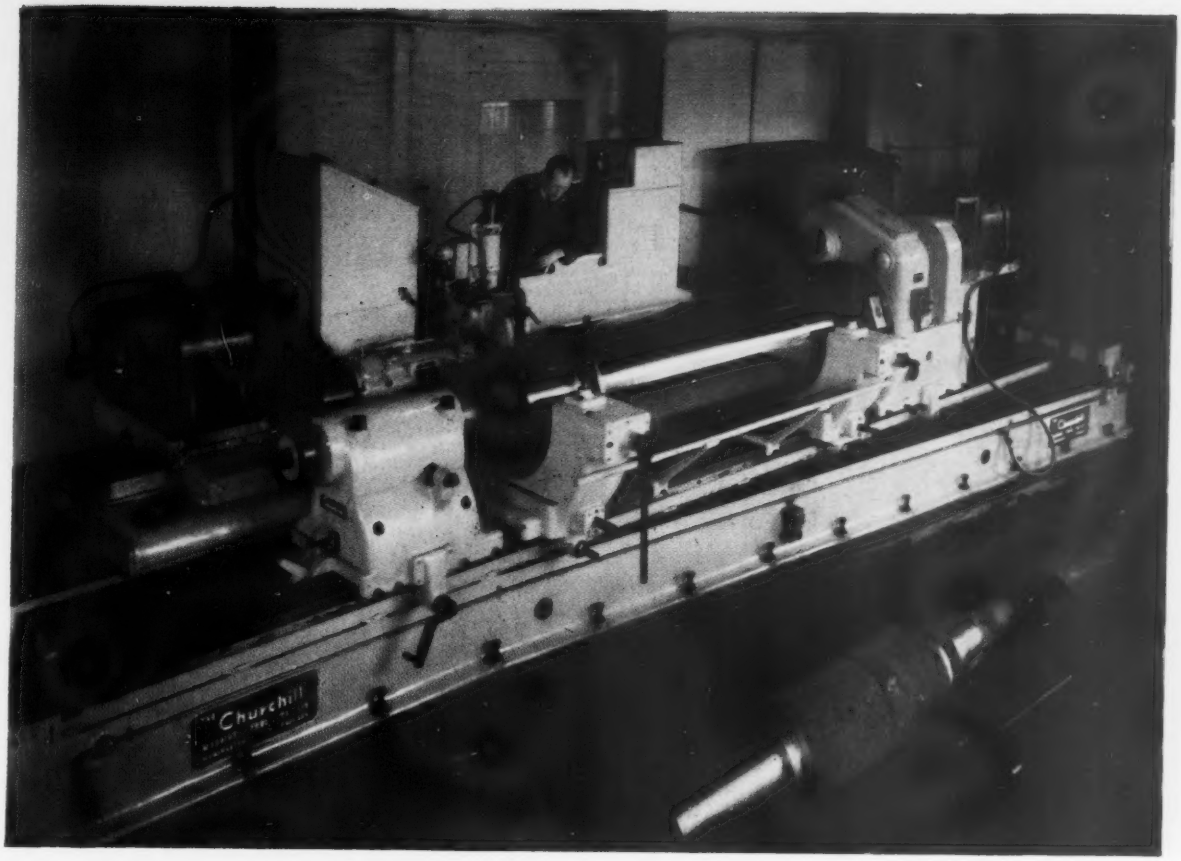

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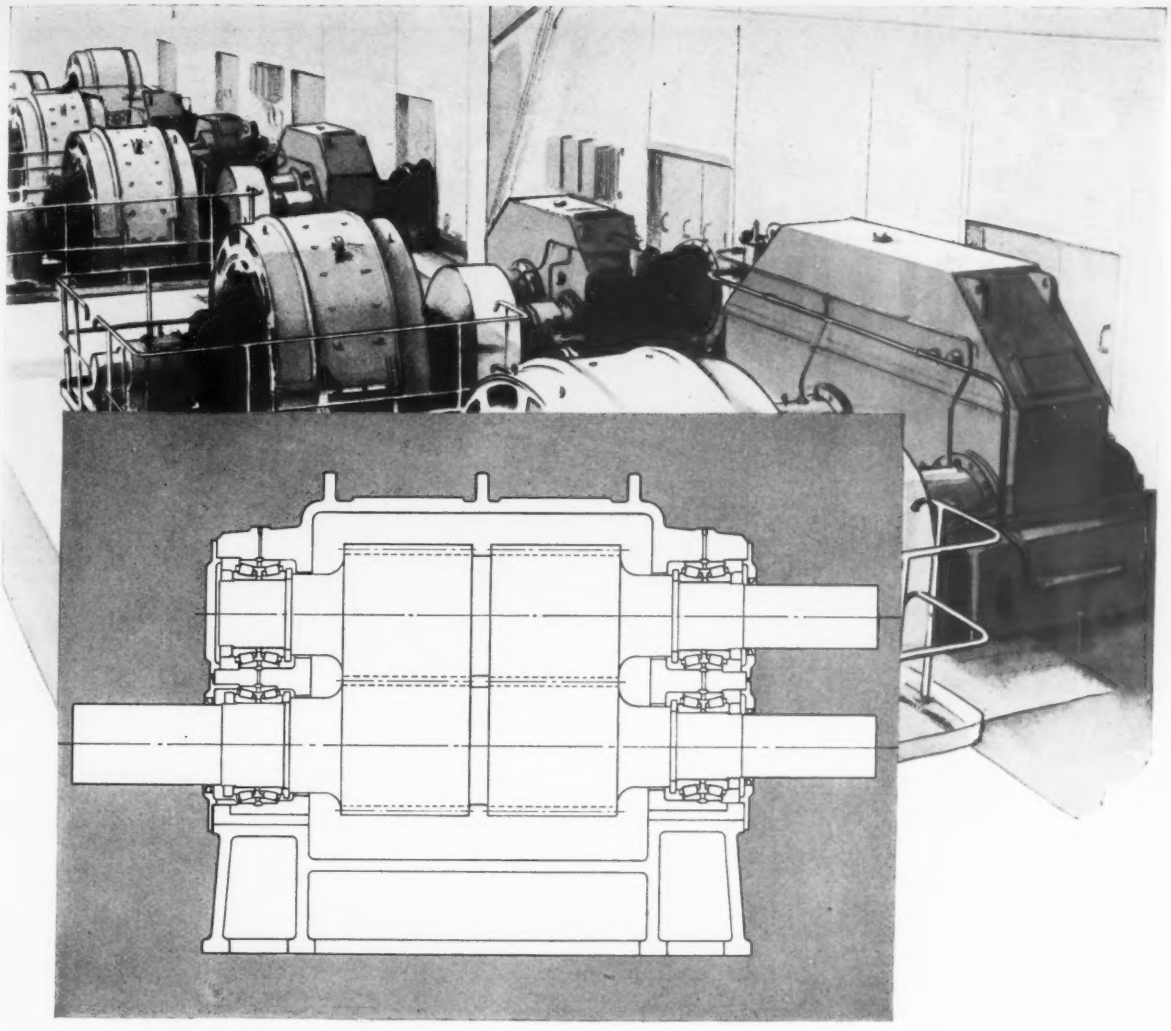

Timken bearings in gear drives for a hot strip mill

The illustration shows the mill motors and gear drives for the finishing stands of the hot strip mill, which was supplied by The Loewy Engineering Company Ltd., Bournemouth, to Forges de la Providence, France.

The gear units and mill pinion housings were made by Turbine Gears Ltd., and the double-helical gears are equipped with Timken double-row tapered-roller bearings.

The sectional drawing shows a typical application of Timken bearings to a two-high pinion stand.

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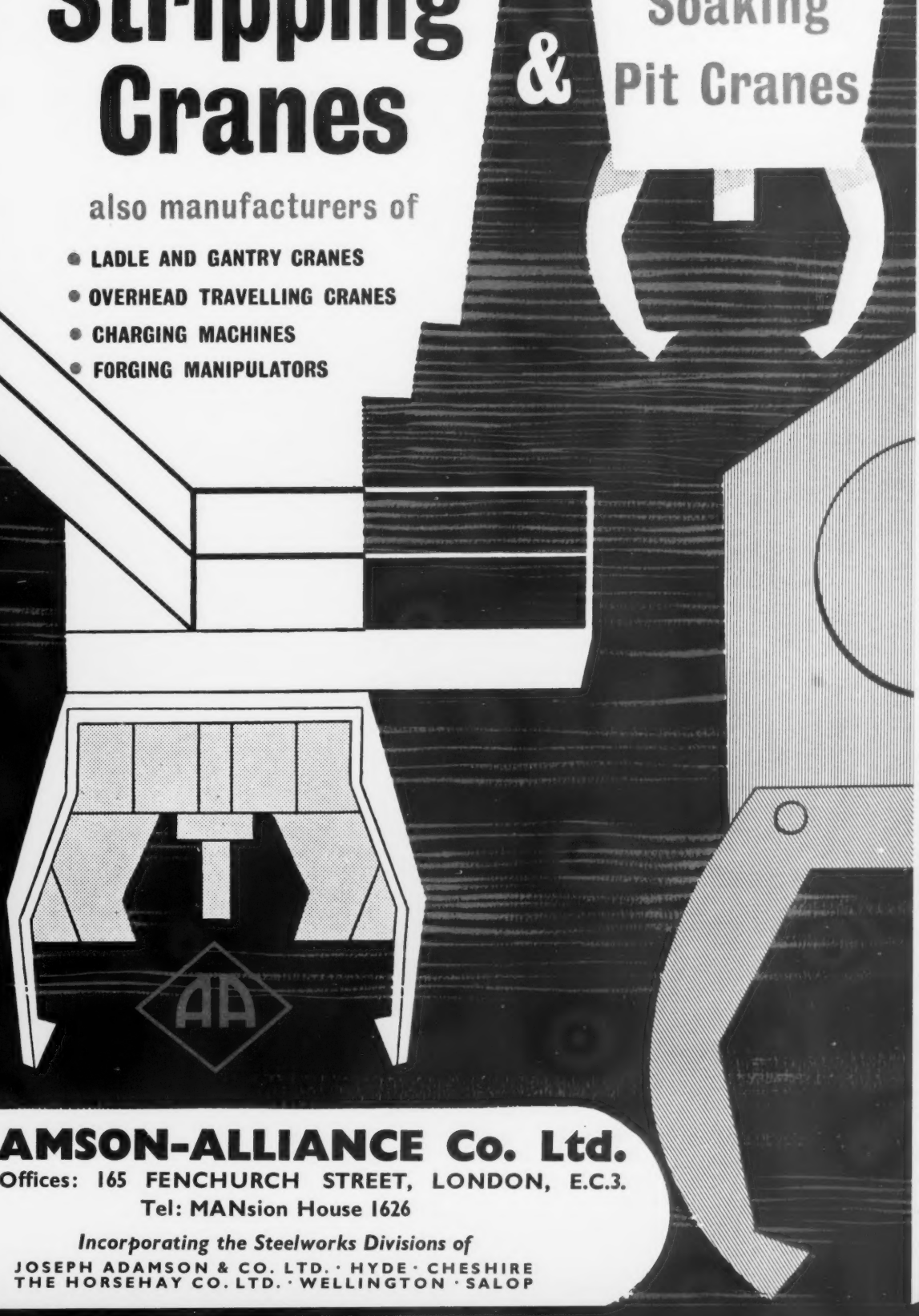

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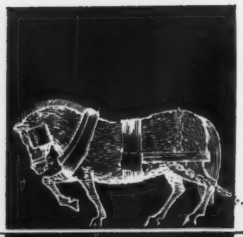
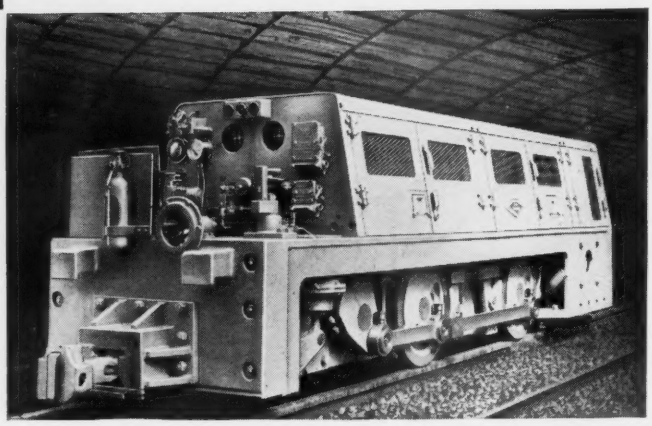


power in harness



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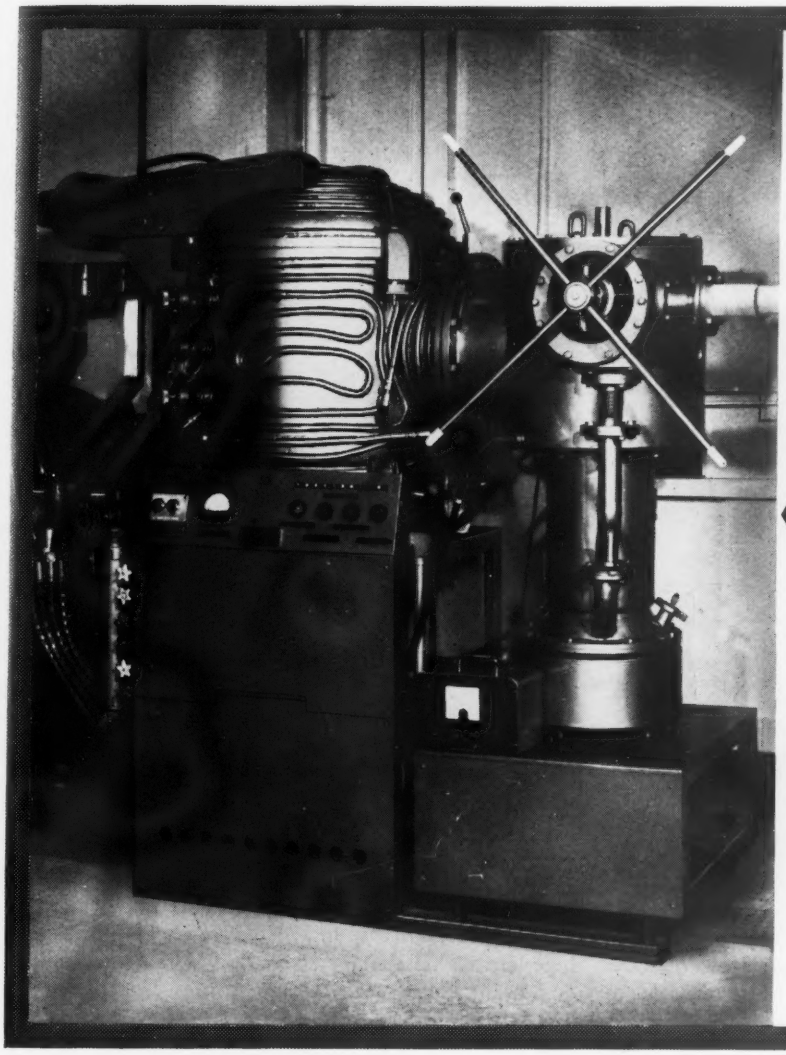

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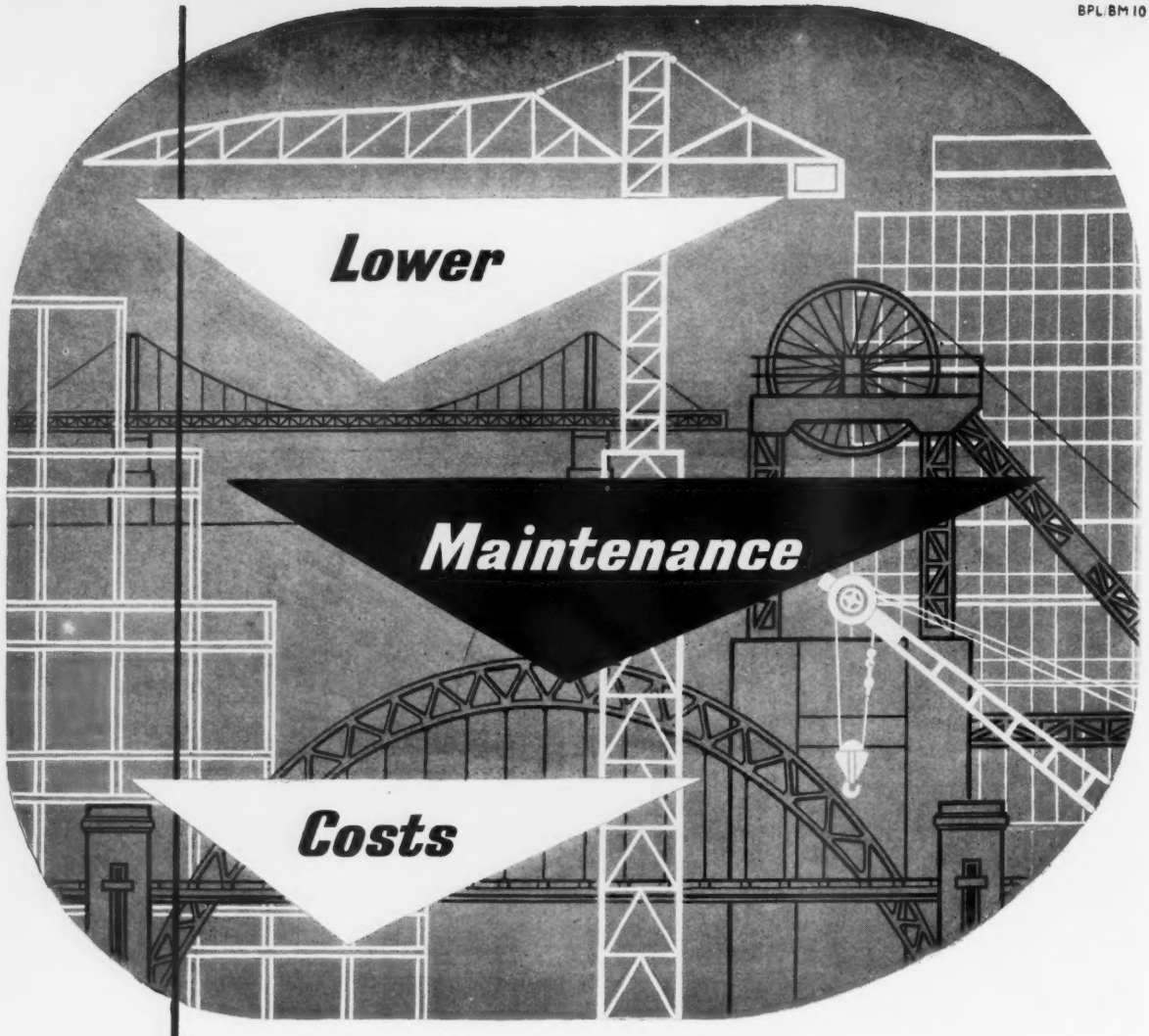

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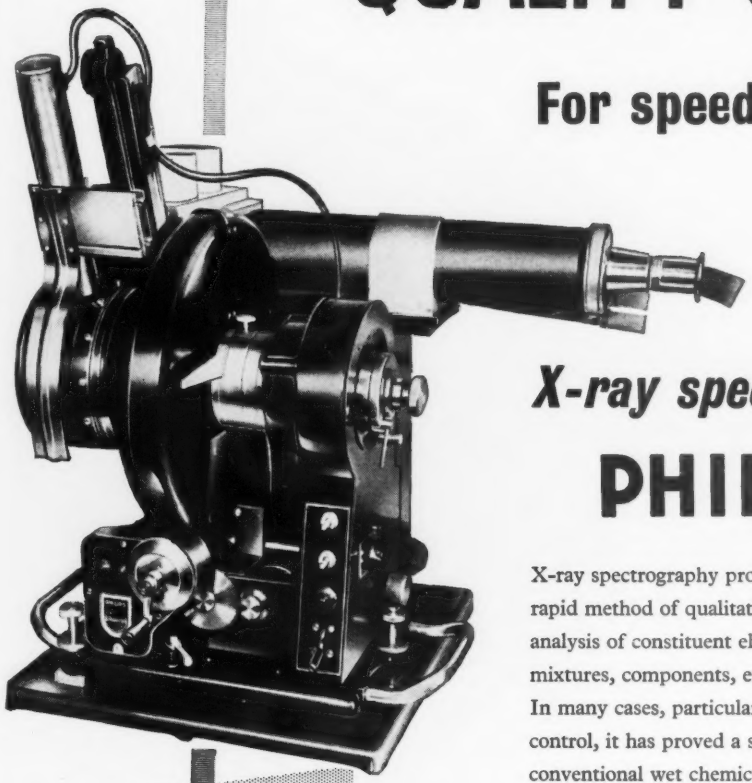

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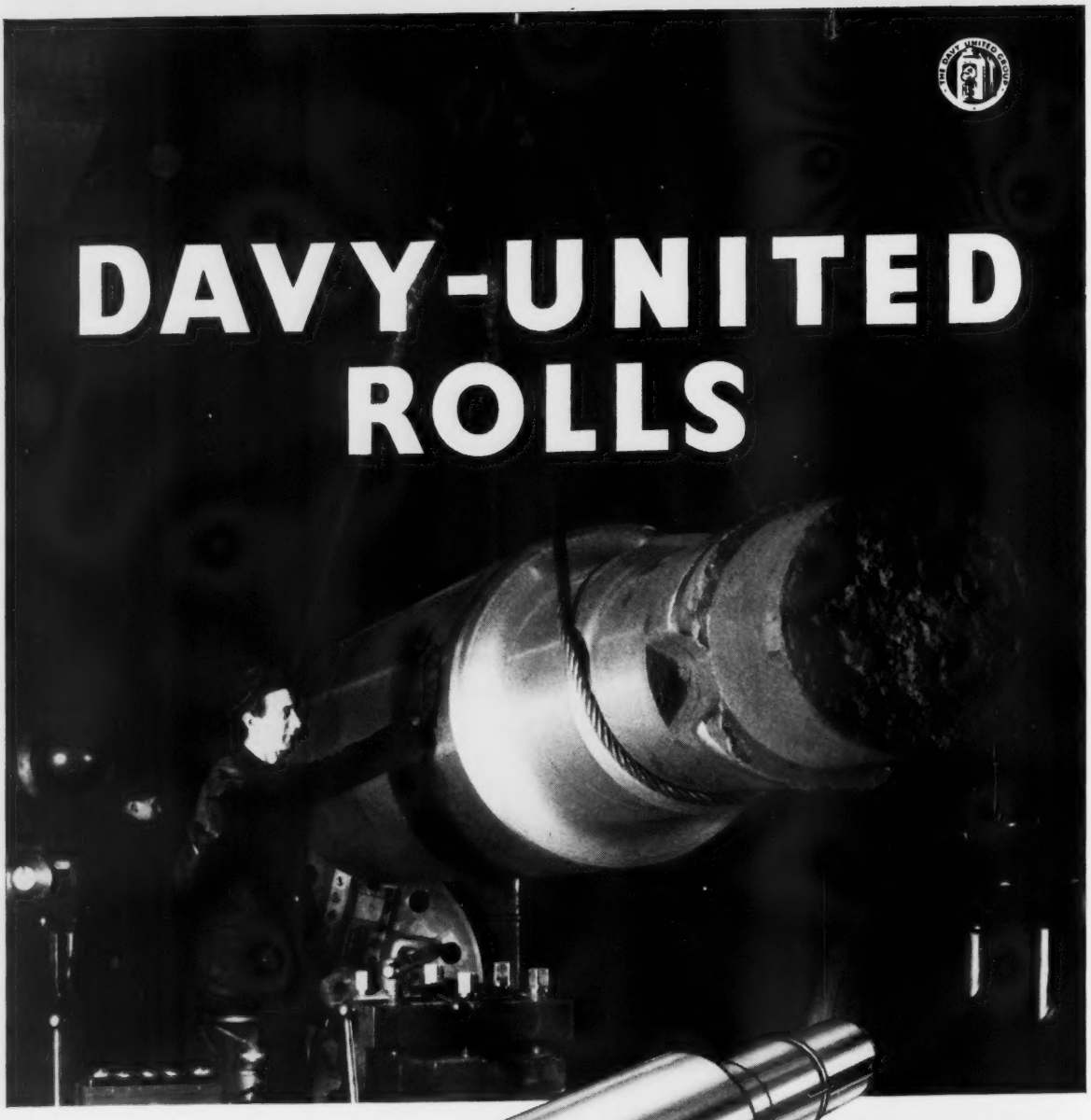

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Professor A. G. QUARRELL, D.Sc., Ph.D., A.R.C.S., D.I.C.

ARTHUR GEORGE QUARRELL was born at Swindon in 1910. He graduated from the Imperial College of Science and Technology with honours in physics in 1932, and worked until 1936 with Professor G. I. Finch in the Department of Chemical Technology on the development and application of electron diffraction. He was awarded his Ph.D. by London University in 1933, and subsequently became D.Sc. in 1944.

Dr. Quarrell was introduced to metallurgy by Professor J. H. Andrew when he became the latter's research assistant in 1936. He was Assistant Lecturer in Metallurgy at Sheffield University from 1937 to 1940, and Lecturer from 1940 to 1945. In 1945 he joined the British Non-Ferrous Metals Research Association; after six months as Senior Metallurgist, he became Research Manager, a post he held until 1950, when he was appointed Professor of Physical Metallurgy at Sheffield University. He took up his present position as Professor of Metallurgy at the same University in 1954.

During his varied career, Dr. Quarrell's researches have included such subjects as the oxidation of iron and steel at elevated temperatures using electron diffraction methods, hairline crack formation in alloy steels, hydrogen embrittlement, slag–metal reactions and dephosphorization, graphitization in steel, and sub-structures in ferrite. His current investigations are concerned with carbides in ferritic steels, structural changes brought about by creep, and the effect of hydrogen on martensite formation in steels.

Dr. Quarrell has served on the Councils of the Physical Society, The Institute of Metals, and The Institution of Metallurgists; he is a Fellow of the Institution and of the Institute of Physics. At present he is a Member of Council and a Member of the Research Board of the British Non-Ferrous Metals Research Association and Chairman of its Industry Committee for Metallurgy of Nuclear Energy. He is also Chairman of the Inter-Services Metallurgical Research Council, and Honorary Consultant to the U.K.A.E.A. He is a Vice-President of the Sheffield Metallurgical Association and a Member of Council of the Sheffield Society of Engineers and Metallurgists.

Dr. Quarrell represents The Iron and Steel Institute on the Council of the British Iron and Steel Research Association, and was elected a Member of Council of The Iron and Steel Institute in 1956.

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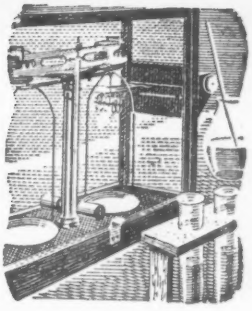

The Effect of Silicon on the Solubility of Nitrogen in Alpha- and Gamma-Iron

By R. Rawlings, Ph.D., A.I.M.

SYNOPSIS

The effect of silicon on nitrogen solubility in iron in the temperature range 700–1000° C has been determined by nitriding in partially dissociated ammonia. For low silicon contents the solubility in both the gamma-phase and the alpha-phase may be expressed by the equation $\log S_x/S_0 = -Ax$, where S_x and S_0 are the solubilities in the iron–silicon alloy and in iron respectively and x is the atomic fraction of silicon. The value of A decreases with increase in temperature and is larger for the alpha-phase than for the gamma-phase. 1315

Introduction

THE RESULTS reported here form part of a programme dealing with the Fe–Si–N phase diagram. The present results deal with the variation of the solubility of nitrogen with silicon content at various temperatures. Later results will deal with the location of the phase boundaries in the system.

According to Darken, Smith, and Filer,[1] the temperature variation of the solubility in the γ-phase may be represented by the equation

$$[\text{N}]\ \text{wt-}\% = 0{\cdot}0404 - 1{\cdot}2x10^{-6}\ T \quad \ldots\ldots(1)$$

where T is the absolute temperature. This equation represents their own results and agrees with previous work and with more recent work.[2, 3] It is therefore quite well established and gives the solubility at one atmosphere with a probable error of $\pm 0{\cdot}001$.

Previous work on the solubility in the α-phase has recently been fully reviewed by Rawlings and Tambini.[5] They summarized all known results by the equation

$$\log [\text{N}] = \frac{-1590}{T} - 1{\cdot}02 \quad \ldots\ldots(2)$$

However, two sets of the results reviewed did not agree and, as they appeared to be equally accurate, their equations are repeated here. Corney and Turkdogan[3] represented their results by the equation

$$\log [\text{N}] = \frac{-1980}{T} - 0{\cdot}795 \quad \ldots\ldots(3)$$

while Fast and Verrijp represented their results by the equation

$$\log [\text{N}] = \frac{-1572}{T} - 1{\cdot}01 \quad \ldots\ldots(4)$$

Values obtained by use of equation (2) lie between those from (3) and (4).

Martin[4] carried out work using alloys of four different silicon contents (*see* Fig. 1). The results show a general decrease in solubility of nitrogen with increase in silicon content. There are however two exceptions:

(i) the 0·55% Si alloy dissolves more nitrogen than does pure iron both in the γ- and α-states

(ii) the solubility of nitrogen in the 3·05% Si alloy (α-phase) is consistently higher than that of both the 1·68% Si alloy and the 5·7% Si alloy.

From present knowledge it is possible that this second anomaly is due to the formation of silicon nitride.

Recent work by Darken, Smith, and Filer[1] using a 0·2% Si and a 0·58% Si alloy do not show any increase in solubility for the 0·58% Si alloy. The γ-phase only was investigated and a slight but consistent decrease in solubility was found with increase of silicon content at several temperatures. Thus it seems likely that the results for Martin's 0·55% Si alloy are in error. For higher silicon contents, Darken *et al.* failed to obtain any consistent results owing to the oxidation of silicon forming a surface film of silica.

DETAILS OF PRESENT METHOD

All previous work has been carried out by suspending the specimen in nitrogen gas at a pressure of one atmosphere of nitrogren, with sometimes a small concentration of hydrogen to prevent oxidation. In view of the difficulties in preventing the oxidation of silicon,[1] it was decided to use partially cracked ammonia as a nitriding medium. From the composition of the gas, one could then calculate the effective partial pressure of nitrogen. However, it was found

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that, with the particular apparatus and gas flows used, the ammonia content of the gas entering the furnace tube was significantly greater than that leaving the tube owing to cracking of the gas on the tube walls. Modification could have been made to prevent this, but another method of attack was used which gave more extensive results. Several specimens of differing silicon contents were suspended in the furnace tube, together with one of pure iron, for a suitable time at the appropriate temperature. From the analyses, one may plot nitrogen content against silicon content, since all the specimens were subjected to the same effective nitrogen pressure. From the knowledge of the solubility of nitrogen in γ-iron, one can calculate the solubility in Fe–Si alloys. An advantage of this method over that using one atmosphere pressure of nitrogen is that higher nitrogen contents are obtained in the iron with a consequent improvement in accuracy.

Ammonia supplied by a cylinder was passed through a steel tube (cracker) heated to a temperature between 500° and 700° C and thence through two silica tubes in parallel containing the specimens heated to the appropriate temperature. The cracker furnace temperature was controlled to $\pm$ 5° C and the nitriding furnace (containing the specimen) to $\pm$ 2° C. The temperature variation along the length (2 in.) of the specimens was about 5° C, being slightly higher at the highest temperature and lower at the lowest.

The high-purity iron used was supplied by B.I.S.R.A.* and the silicon used was 99·90% pure or better. Ingots of 700 g and of several compositions were prepared in a sillimanite crucible using a H.F. furnace. They were then forged, hot-rolled, pickled, and cold-rolled to about 0·015 in. thick. This thickness was chosen as giving a reasonable weight of material for analysis of nitrogen, while being thin enough to allow diffusion of nitrogen from the surface to the centre in practicable times.

Preliminary experiments in which equilibrium was approached both from above and from below gave some idea of the times necessary to produce homogeneous specimens. Metallographic examination of specimens served as a check as to the efficacy of the treatment. In general, the times actually used were somewhat arbitrary (e.g. overnight, 16 h) but were always longer than was considered necessary. Any lack of homogeneity was usually caused by change in the rate of flow of gas (owing to changes in the room temperature affecting the pressure of the ammonia cylinder). The results from such specimens were disregarded.

Silicon determinations were carried out gravimetrically[12] and, in the case of the lower silicon contents, by an absorptiometric method.[12] The latter determined only the silicon in solid solution, whereas the gravimetric method determines silica as well, which, in the case of the lower silicon contents, amounted to a significant proportion of the total. The compositions of the alloys are given in Table I.

Spectrographic examination of the alloys revealed a trace of aluminium—rather more than was present in the original iron.

Nitrogen contents were determined by the Kjeldahl method (with 1 : 1 hydrochloric acid and, where necessary, a few drops of hydrofluoric acid) using steam distillation followed by titration with N/200 or N/25 hydrochloric acid and borax solutions. Calibration of these solutions was by distillation of a known weight of ammonium molybdate with the appropriate reagents. Ammonium molybdate was used in preference to the more usual ammonium chloride because its higher molecular weight allowed greater amounts to be weighed out with consequent increased accuracy. The accuracy of the nitrogen analyses was between $\pm$ 0·001 for nitrogen contents under 0·1% and $\pm$ 0·01 for 0·5% nitrogen.

RESULTS

γ-phase

1000° C—The times used were 2 h or more. Some of the results for the γ-region are plotted in Fig. 2. Each line is drawn through a set of results for specimens nitrided simultaneously. The nitrogen content at the composition for zero silicon is taken from the plotted line and is now plotted against the nitrogen content of each alloy in turn, as seen in Figs. 3*a–f*.

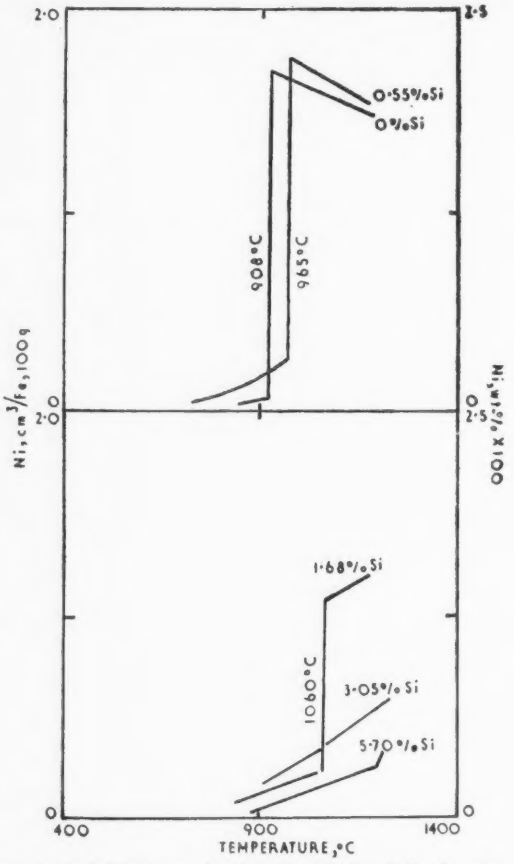


Fig. 1—Solubility of nitrogen in iron and Fe–Si alloy at 1 atm pressure (Martin[4])

* B.I.S.R.A. iron Mark A.G.B.I. Typical analysis: C, 0·004%; Si, 0·002%; S, 0·004%; O, 0·28%; N, 0·01%.

Table I
SILICON CONTENTS OF ALLOYS USED

Method of Determination	Si, wt-%								
	P24	P25	P29	P28	P32	P33	P41	P43	P44
Gravimetric	...	...	0·17	0·29	0·63	0·78	1·03	1·58	1·98
Absorptiometric	0·09	0·05	0·13	0·27	0·57	0·72	...	...	...

In all cases a linear relationship is found, the slopes of the lines increasing with silicon content. The γ-phase is limited at the low-nitrogen end by the formation of the α-phase and at the high-nitrogen end by the formation of silicon nitride. Hence the range of values of nitrogen obtained for the higher-silicon alloys is less than that for the lower-silicon alloys. A consequence of this is that the slopes are known less accurately. From Figs. 3*a–f* one may calculate $\log S(\gamma)/S_o(\gamma)$ for each alloy, where $S(\gamma)$ is the solubility in the silicon–iron alloy and $S_o(\gamma)$ is the solubility in the iron. In Fig. 4, $\log S(\gamma)/S_o(\gamma)$ is seen to vary linearly with silicon content, and

$$\log S(\gamma)/S_o(\gamma) = -6{\cdot}7x$$

where x is the atomic fraction of silicon in the original alloy. Substituting the appropriate value of S_o from equation (1), the equation becomes

$$\log S(\gamma)(1000°\text{C}, p_{N_2} = 1) = \log 0{\cdot}0251 - 6{\cdot}7x \ldots (5)$$

950° C—Results for P33 only were obtained, for which

$$\log S(\gamma)/S_o(\gamma) = -0{\cdot}155 \text{ for } 1{\cdot}44 \text{ at-\% Si}$$

Assuming the linearity found at 1000° C (*see* equation 5) applies in this case, then

$$\log S(\gamma)/S_o(\gamma) = -10{\cdot}8x$$

900° C—A minimum time of 48 h was used for nitriding, while some specimens were nitrided for 96 h. Only the results for the two alloys P29 and P28 (*see* Figs. 5*a* and *b*) were reliable; those for the higher-silicon alloys appeared to show that $\log S(\gamma)/\log S_o(\gamma)$ varied with nitrogen content (*see* Fig. 5*c*).

The results do indicate, however, (*see* Fig. 4) that the effect of silicon content on the solubility of nitrogen in γ-iron is not linear over such a wide range of silicon content as it is at 1000° C. The straight line drawn thus applies to dilute solutions only and its equation, combined with equation (1), gives

$$\log S(\gamma)(900°\text{C}, p_{N_2} = 1) = \log 0{\cdot}0263 - 23x \ldots\ldots (6)$$

800° C and 700° C—Nitriding lasted about 100 h. Alloys of very low silicon content only (P24 and P24) could be used at these temperatures owing to the low solubility of silicon nitride. The results are shown in Figs. 4 and 6, and by the equations

$$\log S(\gamma)(800°\text{C}, p_{N_2} = 1) = \log 0{\cdot}0275 - 69x \ldots\ldots (7)$$

$$\log S(\gamma)(700°\text{C}, p_{N_2} = 1) = \log 0{\cdot}0287 - 190x \ldots\ldots (8)$$

In order to obtain equation (7) and equation (8), a liberty has been taken with equation (1) in obtaining $S_o(\gamma)$ for temperatures below 900° C, as this involves an extrapolation. However, the error is probably negligible because of the small temperature coefficient of S_o. The figures — 69 and — 190, denoting the effect of silicon, should be regarded qualitatively rather than quantitatively. As high nitrogen contents were necessary to obtain the γ-phase, these estimates may be in serious error because of the possibility of $\log S(\gamma)/\log S_o(\gamma)$ varying with nitrogen content. It should be noted that $\log S(\gamma)/\log S_o(\gamma)$ is substantially constant for all nitrogen and silicon contents used to obtain the equations applying to 1000° C and to 900° C.

The results do show however that silicon has an increased effect on the solubility of nitrogen in γ-iron as the temperature is lowered. It follows that the heat of solution of nitrogen in Fe–Si alloys is more positive than in iron. Another result is that the presence of silicon increases the activity of nitrogen in γ-iron and that the interaction coefficient f_N^{Si} decreases with increasing temperature. The value of f_N^{Si} for any particular silicon content may be obtained from the relationship $f_N^{Si} = S_x/S_o$.

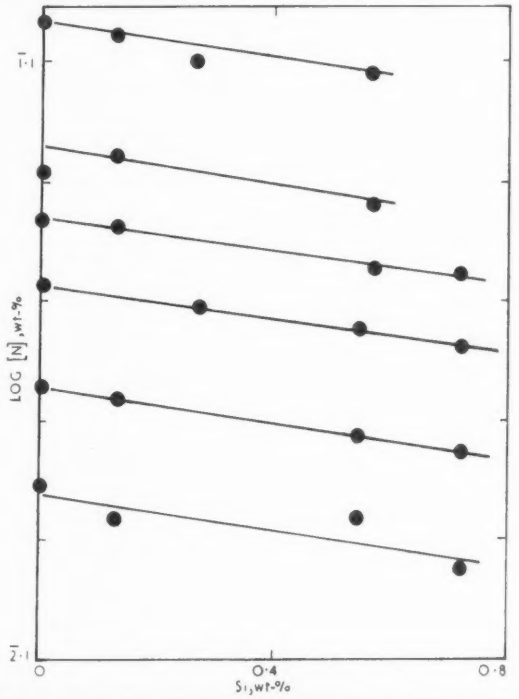
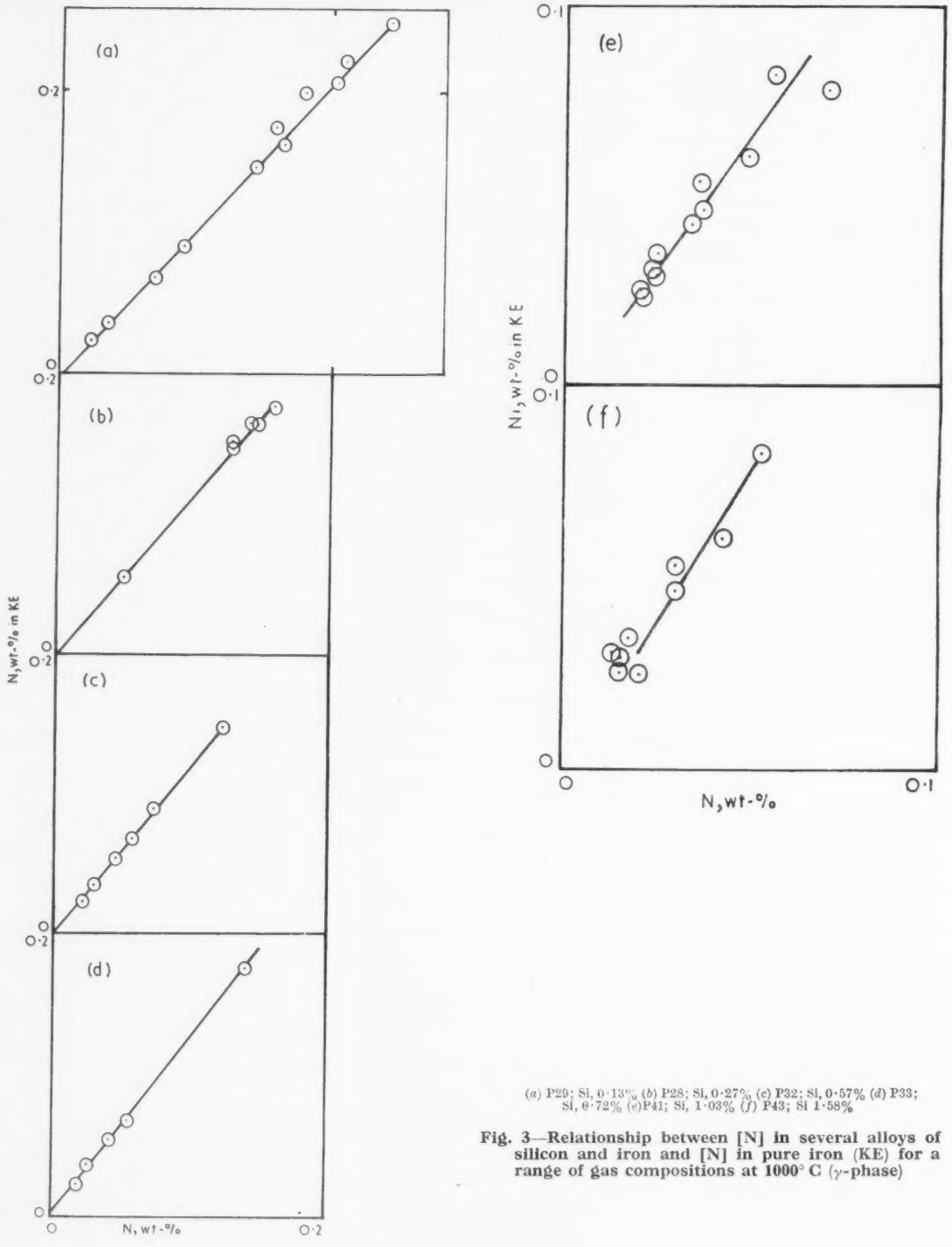


Fig. 2—Variation of nitrogen content with silicon content at several different gas compositions at 1000° C



(*a*) P29; Si, 0·13% (*b*) P28; Si, 0·27% (*c*) P32; Si, 0·57% (*d*) P33; Si, 0·72% (*e*)P41; Si, 1·03% (*f*) P43; Si 1·58%

Fig. 3—Relationship between [N] in several alloys of silicon and iron and [N] in pure iron (KE) for a range of gas compositions at 1000° C (γ-phase)

α-phase

1000° C—Only one alloy, P44 (1·98% Si) was obtained entirely as α at this temperature. The results for this alloy are shown in Fig. 7 and as an equation:

$$\log S(\alpha)/S_o(\gamma)\ (1000^\circ\text{ C}\ 1{\cdot}98\%\ \text{Si}) = 0{\cdot}078 \ldots\ldots\ldots (9)$$

900° C—Results from a number of alloys were obtained and are shown in Figs. 8 and 9. The equation to the line in Fig. 16 is

$$\log S(\alpha)/S_o(\gamma)\ (900^\circ\text{ C}) = -0{\cdot}65 - 30x \ldots\ldots\ldots (10)$$

800° C *and* 700° C—The nitrogen and silicon contents were limited by the formation of the γ-phase or of silicon nitride. The results for 800° C are shown in Fig. 10 and may be represented by the equations

$$\log S(\alpha)/S_o(\alpha)\ (800^\circ\text{ C}) = -\ 95x \ldots\ldots\ldots (11)$$

$$\log S(\alpha)/S_o(\alpha)\ (700^\circ\text{ C}) = -\ 150x \ldots\ldots\ldots (12)$$

Only one set of specimens was obtained as the α-phase at 700° C, their analyses being: KE (0% Si) 0·0215% N; P25 (0·1 at-% Si) 0·0180% N; P24 (0·18 at-% Si) 0·014% N. The figure −150 in equation (12) is thus only approximate.

It should be noted that, in all plots of $S(\alpha)$ against $S_o(\gamma)$ or against $S_o(\alpha)$, the lines do not pass through the origin. This is thought to be explained by the formation of a stable nitride with a low solubility in the α-phase, e.g. AlN. A concentration of only 0·002% Al in the alloy in excess of that in the pure iron would be sufficient to account for the discrepancy in most cases. The spectrographic results support this explanation.

The results for the α-phase show that the presence of silicon has a greater effect on the solubility of nitrogen in iron at lower temperatures. This contradicts results by Corney and Turkdogan,[3] who found that the solubility of nitrogen in a 2·83% Si iron alloy approached that of nitrogen in iron as the temperature decreased.

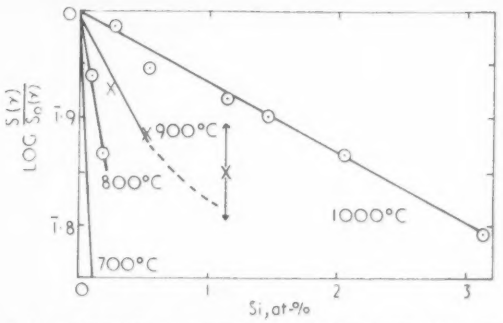


Fig. 4—Solubility of nitrogen in silicon iron $S(\gamma)$, relative to the solubility in iron $S_o(\gamma)$ at various temperatures (γ-phase)

DISCUSSION

γ-phase

By making use of equations (5)–(8), it is possible to calculate the solubility of nitrogen in various Si–Fe alloys. It must be remembered, however, that the equations for the lower temperatures apply to alloys of very low silicon contents only. The calculated solubilities in the 0·2 at-% and 0·5 at-% Si alloys are shown in Fig. 11 for comparison with solubility in pure iron. Some of the alloys are of course hypothetical, in that the γ-phase would not be formed for $p_{N_2} = 1$. In spite of this, one can see that the solu-

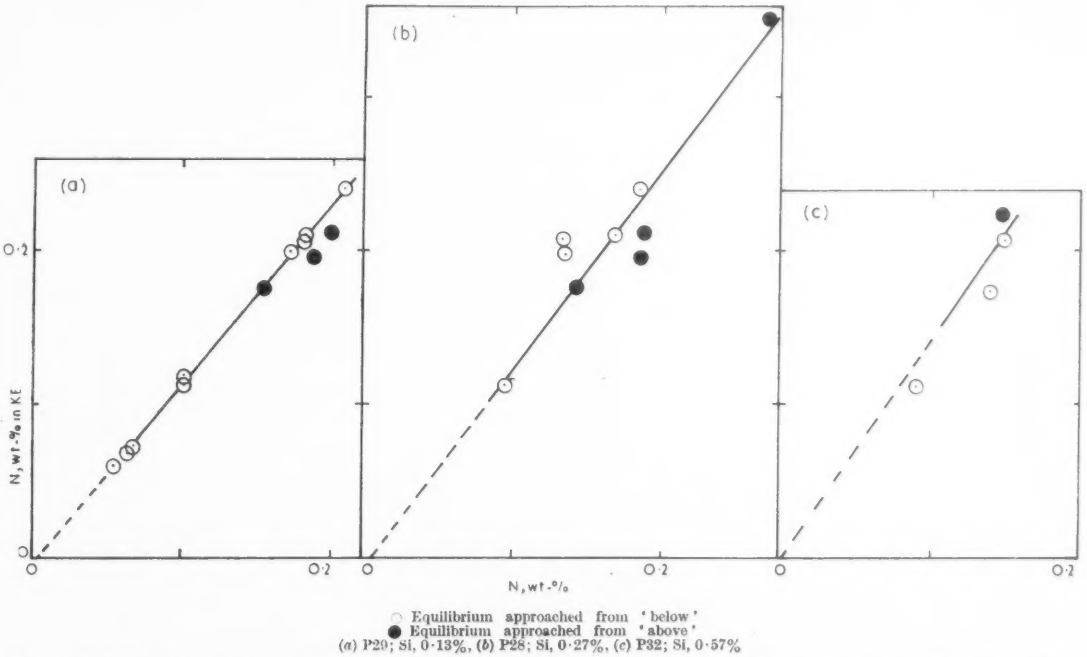


Fig. 5—Relationship between [N] in several alloys of silicon and iron and [N] in pure iron (KE) for a range of gas compositions at 900° C (γ-phase)

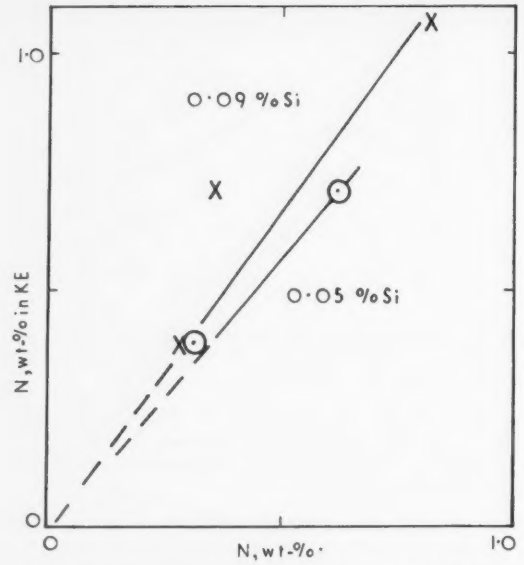


Fig. 6.—Relationship between [N] in dilute Fe–Si alloys and [N] in pure iron (KE) at 800° C (γ-phase)

bility/temperature curve shows a maximum, and that the temperature corresponding to the maximum increases with silicon content. Use has been made of the results of Darken *et al.*[1] for temperatures above 1000° C after interpolating to 0·2 at-% Si and 0·5 at-% Si.

Martin's result for a 3·3 at-% Si (1·68 wt-%) alloy shows a continual increase in solubility with temperature, as opposed to the continual decrease for γ-iron. This is consistent with the present results.

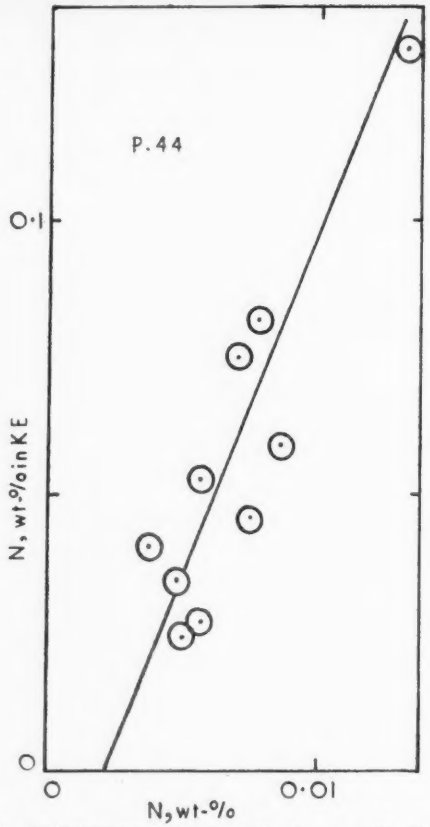
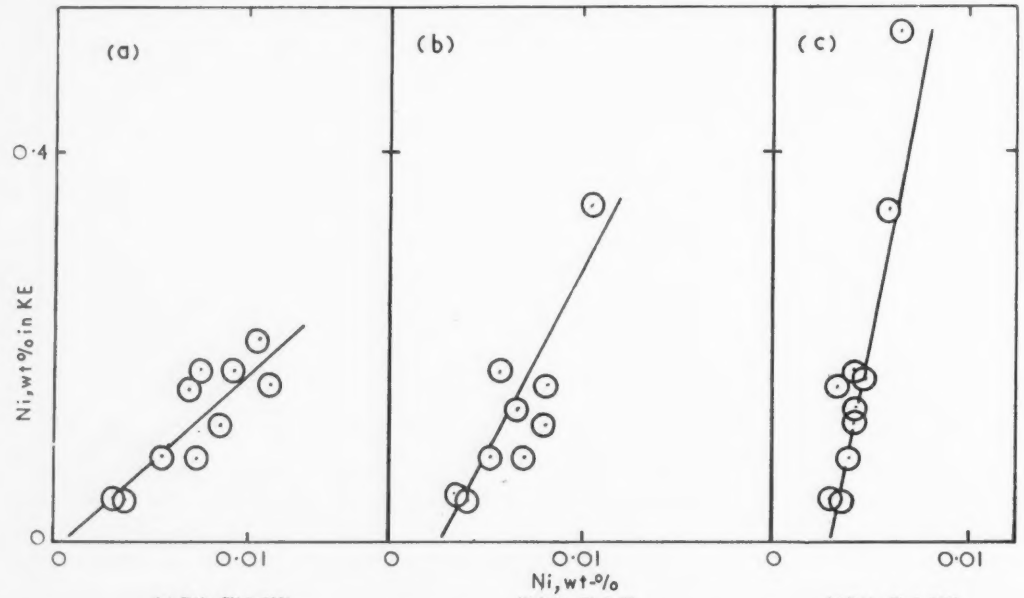


Fig. 7—Relationship between [N] in a 1·98% silicon-iron alloy (α-phase) and [N] in pure iron (KE) at 1000° C (γ-phase)



(*a*) P41 : Si 1·03% (*b*) P43 : Si. 1·58 (*c*) P44 : Si. 1·98%

Fig. 8—Relationship between [N] in several Si–Fe alloys (α-phase) and [N] in pure iron (KE) at 900° C (γ-phase)

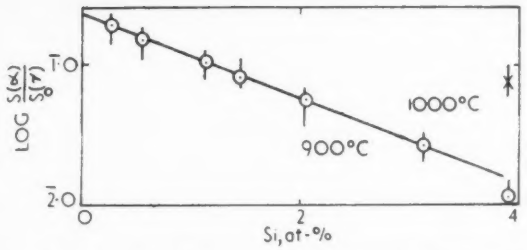


Fig. 9—Solubility of nitrogen in silicon-iron relative to the solubility in iron at 900° C (α-phase)

Since Martin's result for pure iron is low,[1] it may be assumed that his result for the 3·3 at-% Si alloy is also low. A ' correction ', proportional to his error for the pure iron, has therefore been applied as shown in Fig. 11. The new line is in good agreement with the values for 1000° C and 950° C obtained from the present work using equation (5). However, not much reliance can be placed upon this agreement.

It is interesting to note that the positive slope of the solubility/temperature curve for the alloys of higher silicon content may be expected from consideration of the γ-loop. The following is put forward as a tentative argument. Consider an alloy of iron and silicon within the $\alpha + \gamma$ area, containing an infinitesimal concentration of nitrogen. The activity of the nitrogen is the same in both phases under equilibrium conditions. At the extremities of the loop, the composition of the two phases is independent of temperature, so that, for an alloy in the two-phase region, $\partial a_N/\partial_T(\gamma) = \partial a_N/\partial_T(\alpha)$ in order that the two phases remain in equilibrium. It follows that the variation of solubility with temperature must be the same in both phases. Thus, since the solubility/temperature curves for all α-iron–silicon alloys have

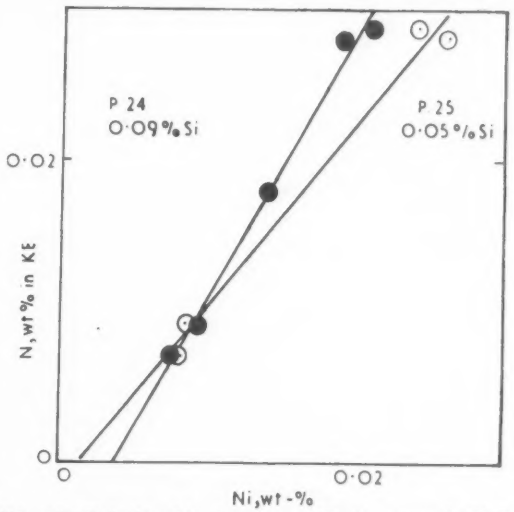


Fig. 10—Relationship between [N] in several Si–Fe alloys and [N] in pure iron (KE) at 800° C (α-phase)

a positive slope, it follows that the curves for alloys of the highest silicon content in the γ region must also have a positive slope at temperatures in the region of 1100° C. Unfortunately, the results are not sufficient to give a quantitative demonstration of this.

α-phase

For 900° C, we make use of equations (1) and (10) to obtain the relationship

$$\log S(\alpha)(900^\circ\text{C}, p_{N_2} = 1) = -2{\cdot}23 - 30x \ldots (13)$$

This gives the solubility of nitrogen in α-iron ($x = 0$) as 0·0059 wt-%. This value is much higher

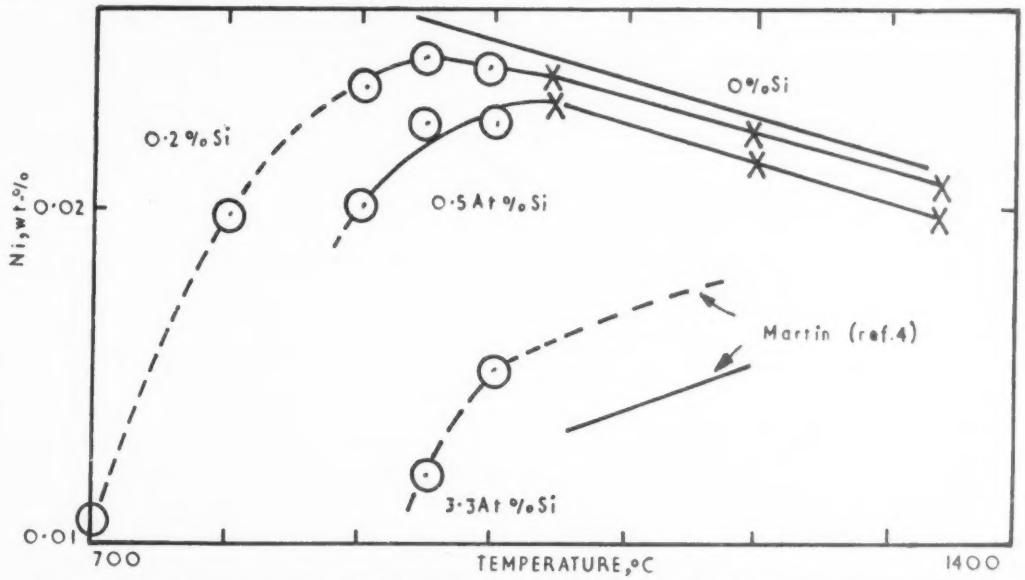


Fig. 11—Temperature/solubility curves for nitrogen in γ-iron; solubility in pure iron and points marked × are from Darken, Smith, and Filer[1] and points marked ○ from present work by interpolation

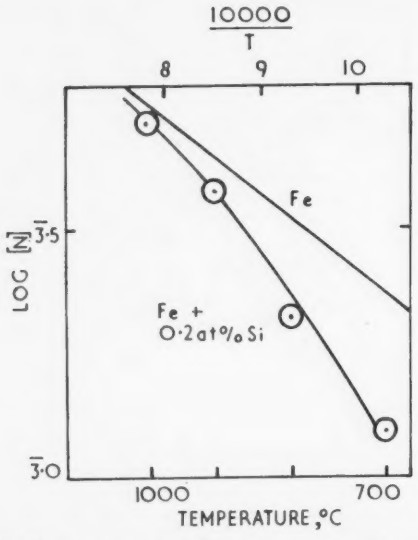


Fig. 12—Temperature/solubility curves for nitrogen in α-iron; solubility in pure iron from Fast and Verrijp[2]

than previous estimates: Rawlings and Tambini equation (2), 0·0043%; Corney and Turkdogan equation (3), 0·0031%; Fast and Verrijp equation (4), 0·0045%. Examination of the line drawn in Fig. 16 indicates that the line could be redrawn to give a figure of 0·0045% N, but no lower. This suggests that the results of Corney and Turkdogan are about 33% too low. The equation by Fast and Verrijp is thus probably the most accurate and is used in the following calculations. First, equation (13) is revised to conform with equation (4):

$$\log S(\alpha)(900^\circ\text{ C}, p_{N_2} = 1) = -2{\cdot}35 - 25x \ldots (13a)$$

Making use of equations (1) and (9), we find that the solubility of nitrogen in P44 (3·89 at-%) at 1000° C is 0·00196 wt-% N. This is lower than previous estimates: Martin,[4] 0·0028% for a 3·3 at-% Si alloy (*see* Fig. 1) and, more recently, Corney and Turkdogan,[3] 0·0021 for a 5·5 at-% Si alloy. It is also much lower than the solubility in α-iron (metastable) at 1000° C calculated to be 0·0057 wt-% from equation (4).

Since the effect of silicon up to about 3·5 at-% on the solubility of nitrogen is linear in alloys at 900° C, it may be assumed that it is also linear at 1000° C. Thus from the result for P44 and equation (4) we see that

$$\log S(\alpha)(1000^\circ\text{ C}, p_{N_2} = 1) = -2{\cdot}245 - 11{\cdot}8x \ldots (14)$$

At 800° C, the solubility in α-iron is 0·0033 wt-% N (equation (4)), which figure, combined with equation (11), gives

$$\log S(\alpha)(800^\circ\text{ C}, p_{N_2} = 1) = -2{\cdot}475 - 95x \ldots (15)$$

Similarly, at 700° C the solubility in α-iron from equation (4) is 0·0024 wt-%, which, together with equation (12), gives

$$\log S(\alpha)(700^\circ\text{ C}, p_{N_2} = 1) = -2{\cdot}625 - 150x \ldots (16)$$

It should be remembered that equations (15) and (16) apply to the range 0–0·2 at-% only.

A solubility/temperature curve for a hypothetical 0·2 at-% Si alloy has been plotted in Fig. 12 using the above equations.

It is interesting to compare the effect of silicon on the solubility of nitrogen in α- and γ-iron with that of the effect of silicon on the solubility of graphite in α- and γ-iron. Data for a temperature of 1000° C are provided in a paper by Smith.[6] The values of A in the equation

$$\log S/S_o = -Ax$$

for low-carbon alloys are given in Table II.

In the case of both nitrogen and carbon, the value of A for the α solution is about 1·7 times that for the γ solutions.

Values of A applicable to the γ-phase for temperatures of over 1000° C have been calculated from Martin's results for his 0% Si and 3·3 at-% Si alloys. These together with the present results are shown in Fig. 13. It is seen that for both the α- and γ-phases the value of A appears to approach a limiting low value at high temperatures. The single result for liquid-iron–silicon alloys by Darken and Gurry[7] supports this statement. Values of A have not been calculated from the results of Darken *et al.*, as the silicon contents they used were not high enough to give accurate values. On the other hand, although as previously noted the solubility results by Martin are low, the value of A can be expected to be quite accurate because of the relatively high silicon content used.

The results of this work show that the presence of silicon causes a marked lowering on the solubility of nitrogen in iron and that the effect is greater at the lower temperatures. This is not easy to understand since silicon forms a very stable nitride, whereas vanadium and chromium, which also form stable nitrides, increased the solubility of nitrogen when added to iron. While no explanation of these results can be offered, it is interesting to note certain other results which have some bearing on the problem. Most pertinent are the results of Leak, Thomas, and Leake,[8] who carried out internal friction measurements on the same Fe–Si–N alloys. These results show, according to the authors, that nitrogen atoms have a preference for Fe–Si sites (i.e. the cotahedral site between an iron and a silicon atom) rather than for Fe–Fe sites. Further, the proportion of nitrogen atoms occupying Fe–Si sites increases as temperature is lowered. This increased preference for Fe–Si sites at lower temperatures is accompanied, as shown by the present results, by an increased effect of silicon in lowering the solubility of nitrogen.

Table II

VALUES OF A AT 1000° C

	N	C (Smith)
α-solution	11·8	5·75
γ-solution	6·7	3·5

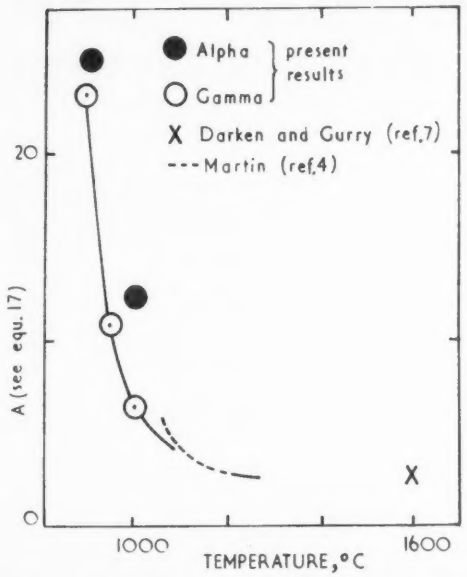


Fig. 13—Temperature variation of A in the equation $\log S(\gamma)/S_o(\gamma) = -Ax$ and $\log S(\alpha)/S_o(\alpha) = -Ax$

Silicon dissolved in iron, both liquid[10] and solid,[9] shows a marked negative deviation from Raoult's Law, indicating a strong preference for Fe–Si bonds rather than Fe–Fe bonds. Since the activity coefficient decreases with decrease in temperature, presumably the number of Fe–Si bonds increases. Moreover, the activity coefficient of silicon in α-iron is less than that in γ-iron (this is easily demonstrated by examination of the γ-loop), indicating a larger proportion of unlike pairs in the α-phase than in the γ-phase.

It appears then that an increase in the proportion of unlike pairs of atoms produces or is associated with a decrease in the solubility of nitrogen in the alloy.

There seems to be an anachronism here, in that Leak, Thomas, and Leake[8] have shown that nitrogen atoms prefer Fe–Si sites to Fe–Fe sites, so that one might expect an increase in the proportion of the former to lead to an increase in solubility, not a decrease.

CONCLUSIONS

The effect of silicon on the solubility of nitrogen in dilute Fe–Si alloys may be represented by an equation of the type

$$\log S_x = \log S_o - Ax \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

where S_x and S_o are the solubilities in the alloy and in pure iron respectively, and x is the atomic fraction of silicon in the alloy. The equation applies to dilute solutions only, the maximum value of x for which it is valid decreasing with temperature.

The results are discussed qualitatively in terms of the negative deviation of silicon from Raoult's Law in Fe–Si alloys.

Values of A are given in Table III and in Fig. 13.

The values of A at 1000° C for the Fe–Si–N system are of the same order as those calculated from the results of Smith[6] for the Fe–Si–C system. In both vases $A\ (\alpha) = 1{\cdot}7xA\ (\gamma)$ approximately (*see* Table II).

Table III
VALUES OF A USED IN EQUATION (17)

	700° C	800° C	900° C	950° C	1000° C
α-phase	150	95	25	...	11·8
γ-phase	190	69	23	11	6·8

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Scaling of 18–8 Stainless Steel in Reheating Furnace Atmospheres

By John Olof Edström

SYNOPSIS

The structure of oxide scales formed on 18–8 stainless steels at 1050° C and in different types of reheating furnace atmospheres have been studied by microscopy and X-ray diffraction. Special attention has been paid to the conditions for formation of flaky and of adherent oxides, and a hypothesis for the mechanism of scaling of this type of stainless steel is presented. An explanation is given of the different influence of sulphur on scaling in atmospheres containing excess of oxygen compared with excess of carbon monoxide or hydrogen. 1400

AT PRESENT most reheating furnaces, at least in Sweden, are oil-fired. Heavy oils, which are comparatively cheap, are often used. The tendency to surface defects on heated steel has increased with the use of the heavy sulphur-rich fuel oils. A difficulty that has become increasingly apparent, especially in the heating of sheet and slabs, is the occasional formation of flaky and brittle oxide films on the steel during heating. This type of oxide scale is easily rolled into the sheet and gives rise to surface defects. On other occasions the oxide films are tough and adherent, which is more favourable from the rolling aspect.

The primary purpose of this investigation has been to elucidate the oxidation conditions under which oxide films become flaky or adherent, and to study the structure and mechanism of formation of the respective films by microscopic and X-ray diffraction methods. An explanation has also been given of the varying influence of sulphur on the oxidation process in oxidizing and reducing types of atmosphere.

OUTLINE OF THE PROCESS OF OXIDATION OF METALS

By way of background to the following discussion of the experimental results arrived at, a brief description will be given of the thermodynamics and kinetics of the reactions involved in oxide formation.

The thermodynamic conditions for oxidation of a metal may be illustrated by diagrams showing how the so-called oxygen potential of the system changes with the oxidation temperature.[1] The oxygen potential is the expression $RT \ln p_{O_2}$, where p_{O_2} is the oxygen pressure. The oxidation equilibria are of the type

$$\text{metal} + O_2 \rightarrow \text{oxide}$$

When both metal and oxide occur as pure, separate phases, the equilibrium constant (K) is obviously equal to the reciprocal value of the equilibrium pressure of the oxygen, and, according to the well-known relationship $\Delta G^\circ = -RT \ln K$, it holds that

$$\Delta G^\circ = RT \ln p_{O_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

ΔG° is the change in the free energy of the system on reaction between the components in standard state. If the oxygen pressure of the gaseous atmosphere exceeds the equilibrium pressure, i.e. if the oxygen potential of the system is greater than ΔG° for the oxide, the metal becomes oxidized; and at pressures below the equilibrium pressure the oxide becomes dissociated. The more noble the metal, the higher is this equilibrium value of the oxygen pressure and the less tendency does the metal have to form oxides or, as it is customarily expressed, the lower is its affinity to oxygen. For reasons which will not be discussed here, the plotting of ΔG° as function of the temperature produces practically straight lines[1] which thus represent the temperature dependence of the oxygen potential.

In Fig. 1 equilibrium lines have been drawn for the oxides of the alloying elements in an ordinary 18–8 steel. Strictly speaking, the graph is valid only for pure metals and oxides (i.e. at unit activity for the solid phases), but it can also be used with a fairly high degree of certainty for the determination of the possibilities of oxidation at other activity values, provided that the deviation from unity is not too great.[2] The oxygen potential lines have been plotted for certain given CO–CO_2 mixtures and for oxygen pressures of 0·1 and 0·01 atm.

If several oxides can be formed by oxidation, an oxide with high oxygen potential forms on the metal surface outside one with lower oxygen potential. Thus if, for example, iron is oxidized with oxygen, wüstite is formed directly on the metal, thereafter magnetite (Fe_3O_4), and, nearest to the oxygen, hematite (Fe_2O_3).

The oxygen potential indicates the condition for formation of oxides, but provides no guidance regarding their rate of formation. Iron, for example, has much less affinity for oxygen than chromium, despite which the former is oxidized at a much greater rate than the latter. This is because the oxides that form on chromium afford a far higher degree of protection against further pickup of oxygen than the oxides forming on iron. The criterion for the rate of oxidation of a metal is not its chemical affinity to oxygen but the structure of the oxide formed on the metal surface.

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Table I
STARTING MATERIALS

Designation	Sandviken Grade	Dimensions of Specimens, mm	Scaling Temp. (air), °C	Specification Analysis, %							Composition Found, %				
				C	Si	Mn	P (max)	S (max)	Cr	Ni	C	Mn	Cr	Ni	Mo
S1	*0R2N10*	0·10 × 17 × 53	875	0·06	0·5	0·4	0·030	0·030	19	10	...	0·44	...	...	...
S2	*0R2N10*	2·3 × 8 × 16	875	0·06	0·5	0·4	0·030	0·030	19	10	0·09	0·40	17·8	8·9	0·12
S3	*2R2N10*	0·25 × 17 × 53	875	0·10	0·5	1·0	0·030	0·030	17·5	10	0·10	0·59	16·9	10·3	0·09
S5	*0R2N10*	0·25 × 17 × 53	875	0·06	0·05	0·4	0·030	0·030	19	10	...	...	...	...	...

Almost all results of kinetic studies of reactions between pure gases and metals can, at least at high temperatures, be expressed by one of the following basic equations[3]:

$$\text{Linear process} \quad \frac{dx}{dt} = k \qquad (2)$$

$$\text{Parabolic process} \quad \frac{dx}{dt} = \frac{k}{x} \qquad (3)$$

$$\text{Exponential process} \quad \frac{dx}{dt} = k_1 . e^{-k_2 x} \qquad (4)$$

Here x is the thickness of the oxide film, t the time, dx/dt the rate of growth of the film, and k constants. The physical interpreation of these laws has been done by Wagner,[4] Mott,[5] Evans,[6, 7] and others. The linear equation denotes that the process is controlled by a phase-boundary reaction, with the formation normally of porous or volatile oxides. The parabolic equation shows that the reaction is controlled by diffusion through the growing, dense oxide film. The exponential equation is valid for a mechanism of gas attack through cracks of varying depth in an otherwise protective oxide film. The equations apply to single oxide films; with multilayer films the process becomes much more difficult to interpret. Equation (3) states that the rate of oxide growth (dx/dt) is inversely proportional to the momentary thickness (x) of the oxide film, and thus that the oxidation proceeds more and more slowly as the film continues to grow. Integrating equation (3) gives the well known parabolic law

$$x^2 = k.t \qquad (5)$$

As mentioned above, equation (3), and thus the parabolic law, hold good for dense oxide films. Often, however, the law can only be applied during the first stage of oxidation. The parabolic process ends abruptly and a period of more rapid oxidation begins. This change is generally attributable to a mechanical rupture of the oxide film through the release of the internal stresses when the film has reached a certain critical thickness. If the film has disintegrated, oxygen in molecular form is enabled to penetrate to the surface of the metal and the oxidation is accelerated. The critical thickness is stated to be greater in slow than in rapid oxidation processes.[8] During the secondary oxidation, dense films which retard oxidation can again be built up, and after a time are themselves broken down, after which the process is repeated.[9] In the oxidation of alloys the protective oxide film may be not only broken down mechanically, but also destroyed 'from within' by chemical reaction with some component in the base metal, whereupon new non-protective oxides are formed.

The mass transport through dense solid oxide films has been interpreted by Wagner[10] as a migration (diffusion) of ions and electrons; migration of electrically neutral atoms or molecules may be disregarded. For diffusion to take place, a concentration gradient or rather an activity gradient must be established across the growing oxide layer. This condition, which is prescribed by Fick's fundamental diffusion laws, requires deviations from the ideal stoichiometric composition of the oxide and, consequently, from a strictly arranged lattice structure. Lattice defects, such as unoccupied lattice sites (vacancies) or interstitial ions and electrons enable the diffusion processes to take place through the oxide films.

To summarize: in order that an oxide film on a pure metal may afford protection against continued oxidation, the following conditions primarily must be fulfilled[11]:

(1) The oxides must form a coherent, non-porous crack-free film on the metal so that all diffusion of gas through the film is prevented

(2) The rates of diffusion of metal and oxygen ions across the film must be small, which agrees with the requirement that the oxides must have low electrical conductivity

(3) The surface oxides must not form low-melting-point eutectics.

Condition (3) has not been dealt with previously, but molten layers, of course, afford no protection. Moreover, the higher the melting point of a compound, the lower are the rates of diffusion in it.

Wagner has not only dealt with the oxidation of pure metals; in a paper [12] in 1952 he made a theoretical analysis of the diffusion processes that are rate-determining in the oxidation of alloys. In this paper he states an essential condition for the formation of only one oxide on an alloy in which both constituents can be oxidized. Diffusion through oxides of aluminium, beryllium, chromium, and silicon proceeds very slowly. Wagner's argument gives guidance as to how an alloy between a basis metal and one of these metals as additives might become oxidation-resistant by the formation of a coherent film of the oxide of the additive metal.

So far external compact oxide scales have been dealt with. Apart from these external scales, an inner oxide-containing layer is often formed during oxidation of alloys, the oxide particles being embedded in the metallic phase. This layer is called 'subscale' and the oxidation process is known as internal oxidation. Subscale is formed by one or more metal constituents reacting preferentially with the oxygen that has diffused into the alloy from the scale/metal

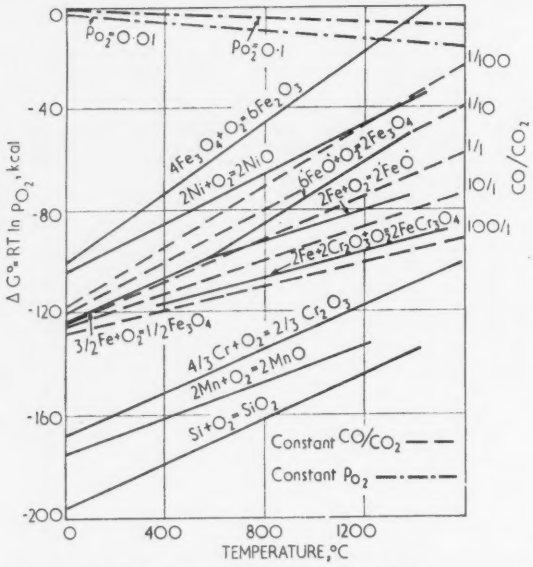


Fig. 1—Oxygen potential diagram

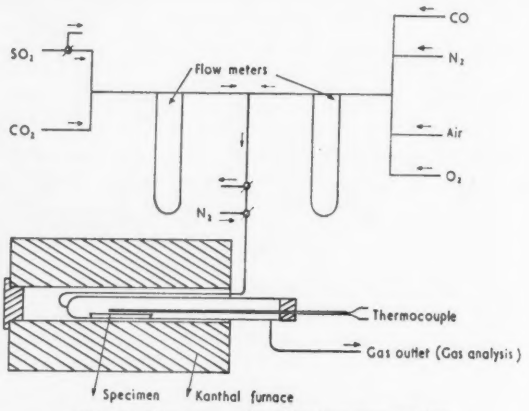


Fig. 2—Diagram of oxidation apparatus

interface under precipitation of oxide particles, while other more noble metal constituents are not affected but remain as metallic phase. The penetration of oxygen proceeds preferentially along the grain boundaries of the alloy, causing intercrystalline attacks. A condition for the formation of subscale is that the diffusion of oxygen into the alloy proceeds more rapidly than the outward diffusion of the comparatively less noble constituent to the outer oxide scale/metal interface. Similar subscales may be caused by sulphur diffusing into an alloy.

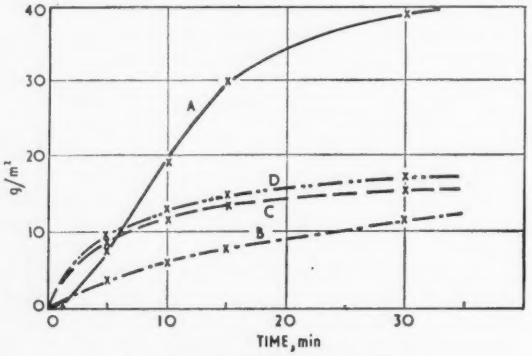
IMPORTANT OXIDE DATA

Figure 1 provides guidance for the determination of what oxides may be formed on an 18–8 steel for different compositions of the oxidizing gas. A calculation is made of the oxygen potential of the gas, $RT \log p_{O_2}$, which is plotted on the diagram. The existing oxygen pressure suffices for the formation of all oxides with oxygen potential below the plotted value.

18–8 steel is an alloy consisting chiefly of iron, chromium, and nickel, and the oxides primarily to be expected are simply oxides of these metals, i.e. wüstite (FeO), Fe_3O_4, Fe_2O_3, Cr_2O_3, and NiO, or combined oxides. The combined oxides may be, for example, of spinel type such as $FeO.Cr_2O_3$ ($FeCr_2O_4$), or of sesquioxide type such as $Fe_2O_3.Cr_2O_3$ ($Fe_2Cr_2O_6$). Both the sesquioxides[13–15] Cr_2O_3 and Fe_2O_3 and the spinels[16] Fe_3O_4 and $FeCr_2O_4$ form mutually complete series of solid solutions.

The steel also contains small quantities of Si, Mn, and Mo, which may, of course, also be oxidized. No oxides from these metals have been observed in the present investigation. However, the literature contains frequent mention of the oxidation rate being very considerably affected by small contents of alloying elements or impurities. In a Canadian investigation,[9] for example, it was shown that, in the oxide scale on chromium steel containing 27% Cr and 0·3% Si, the most abundant constituent after Cr_2O_3 was SiO_2 and that the oxidation resistance of this steel was largely attributable to the formation of SiO_2. It should perhaps be noted, too, that U.S. studies[17] have shown the passive surface film, forming at room temperature on an 18–8 steel with 0·6% Si, to contain about 10% Si. As is known, molybdenum also can have a great influence on the oxidation result,[18,19] but in the 18–8 steel under consideration the molybdenum content was only 0·1% and can hardly be expected to have much influence.

As shown by Fig. 1, Cr_2O_3 has a low oxygen pressure and, with the exception of SiO_2 and MnO, is the most stable of the oxides mentioned here. NiO, on the other hand, is comparatively unstable. The oxygen pressures of both Fe_3O_4 and wüstite are lower than that of NiO. This means that there is little probability of NiO existing in the internal layers of scale on an iron alloy. The iron oxidizes first and nickel remains as metallic phase. Nickel might possibly exist in the external scale as a mixed



A. 15% CO_2, 1·5% CO, 0·1% SO_2, 83% N_2
B. 15% CO_2, 1% CO, 84% N_2
C. 16% CO_2, 1·5% O_2, 0·1% SO_2, 82 N_2
D. 16% CO_2, 1·5 O_2, 82% N_2
Material: *S3*
Temp.: 1050° C

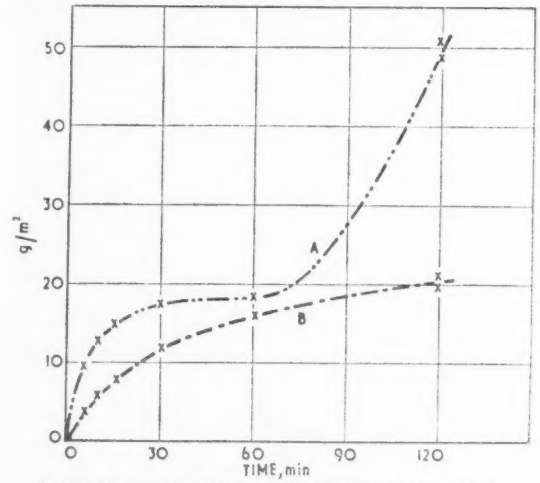
Fig. 3.—Influence of gas composition on oxidation rate. Addition of SO_2 causes a sharp rise in scale formation with excess of CO in the gas, but has no appreciable effect with excess of O_2

oxide of spinel type, e.g. $NiCr_2O_4$, for the oxygen pressure of NiO is lowered by Cr_2O_3. If the steel contains manganese, Mn ions will probably also be introduced into the spinels.

A sulphur-containing atmosphere would naturally tend to form sulphides or sulphide–oxide compounds. These compounds often have a low melting point and may prevent the formation of a protective oxide film. The compounds of nickel with sulphur have especially low melting points. The sulphide Ni_3S_2, for example, melts at 787° C, while $Ni–Ni_3S_2$ forms a eutectic which melts at a temperature[20] as low as 645° C. Dissolution of FeS in the nickel sulphides raises the melting temperature, but low-melting-point compounds are still formed: the sulphide $2FeS.Ni_3S_2$, for example, melts at 880° C. The melting points of the oxysulphides are also low.[21] The conditions for sulphide formation are dealt with in the subsequent discussion on the experimental results.

The mass transport through the oxide phases of present interest will also be touched upon. Through wüstite and magnetite it occurs by means of diffusion of iron ions, and through hematite by diffusion of oxygen ions.[22] The mechanism of diffusion through Cr_2O_3, on the other hand, does not appear to be directly established experimentally. Studies of the electrical conductivity of oxides, however, have indicated that the diffusion occurs through chromium ion vacancies.[23] Oxidation tests with pure Cr metal as starting material have shown that the rates of mass transport through the Cr_2O_3 film are slow.[24]

Spinel phases are built up in different ways and, according to their structure, they manifest different rates of diffusion and electrical conductivity. The compounds have been named after the mineral spinel, $MgAl_2O_4$. They may be formed either according to the formula $[X^{2+}][Y^{3+}{}_2]O_4$ or the formula $[Y^{3+}][X^{2+}Y^{2+}]O_4$. The structure may be thought of as a cubic, close-packed oxygen lattice with the metal ions bedded in some of the interstices between the oxygen ions. The metal ions are much smaller than



A. 16% CO_2, 1·5% O_2, 82% N_2 B. 15% CO_2, 1% CO, 84% N_2
Material: *S3* Temp.: 1050° C

Fig. 4—The 'breakthrough' on oxidation of 18–8 steel in O_2-containing gas

Fig. 5—18% CO_2 + 1·2% CO + 81% N_2, 30 min: thin adherent oxide × 600

the oxygen ions. In a structure based on the first formula, the so-called normal spinels, all trivalent ions occupy octahedral positions in the oxygen lattice surrounded by six oxygen ions, and all divalent ions occupy tetrahedral positions surrounded by four oxygen ions. Spinels with the second type of structure are called 'inverse'. In these spinels the tetrahedral positions are occupied by trivalent ions, and the octahedral by both divalent and trivalent ions. Inverse spinels show higher electrical conductivity and rates of diffusion than normal spinels. Fe_3O_4 is an example of an inverse spinel with high diffusion rate and, on the above principle, would be written $[Fe^{3+}]\ [Fe^{1+}\ Fe^{3+}]O_4$. $FeCr_2O_4$, on the other hand, is a normal spinel[25, 26] and should have a low diffusion rate. The solid solutions of Fe, Cr spinels may be written $FeFe_{(2-x)}\ Cr_x\ O_4 (0 < x < 2)$. According to Yerian, Kortright and Langenheim[16] the structure is normal for stoichiometric oxygen contents from $x = 1·28$ to $x = 2·0$ and inverse from $x = 0$ to $x = 0·3$. Between these regions there is a transition from normal to inverse form in two stages.

Thus on the surface of 18–8 steel a quantity of compounds with very different properties may be formed during oxidation, and it may be expected that different conditions of oxidation will produce highly dissimilar chemical and structural forms in the surface films.

STARTING MATERIALS AND EXPERIMENTAL PROCEDURE

The materials used in this investigation were supplied by Sandvikens Jernverks AB, the compositions being given in Table I. Material *S2* was ground on No. 0 emery and washed in acetone before being oxidized. Materials *S1*, *S3*, and *S5* were supplied in bright annealed condition and directly oxidized without other surface treatment than successive washing in benzene, soapy water, water, and acetone.

Figure 2 shows schematically the apparatus used for carrying out the oxidations. The oxidation temperature was in all experiments 1050° C and the rate of gas flow about 5 cm/s. A heating temperature of 1050° C is normal for an 18–8 steel that is to be hot-rolled. The gas quantities, with the exception of SO_2, were measured with capillary-tube flowmeters and the composition of the gas was checked in an Orsat apparatus. The quantities of SO_2 were too

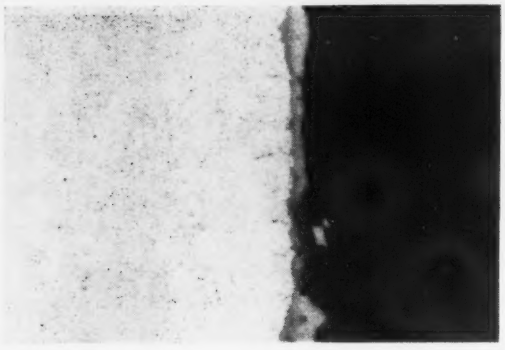


Fig. 6—17% CO_2 + 2·6% O_2 +80 % N_2, 30 min: tendency to flaking. Two oxide layers in the oxide film × 600

small for measurement with a flowmeter and were therefore checked by observation of the rate of bubbling through a washing flask. Adjustment was facilitated by causing the greater part of the gas taken from the cylinder to bypass the furnace. The quantity of SO_2 that corresponded to a given bubbling rate was determined by absorption on soda asbestos and weighing. To maintain the conditions as identical as possible during determinations of oxidation rates, entire series of experiments were made at the same gas flow setting; the oxidizing gases were bypassed only during heating and cooling of the samples, which was always done in nitrogen purified from oxygen.

In some experiments H_2 and H_2O were added to the oxidizing gas. For regulation of the quantities of H_2O a water saturator was used which was adjusted to the temperature corresponding to the desired content of water in the gas. The microspecimens were ground with Al_2O_3 paste on lead discs in a Graton–Vandervilt machine and were polished with diamond paste on cloth. The X-ray studies were made on oxide powder scrapings or directly on the oxidized surfaces of the specimens in an X-ray spectrometer equipped with Geiger–Müller tube. The most appropriate method of examining Fe,Cr oxides is by Cr radiation, but this type of radiation was not available, and Fe or Cu radiation had to be employed.

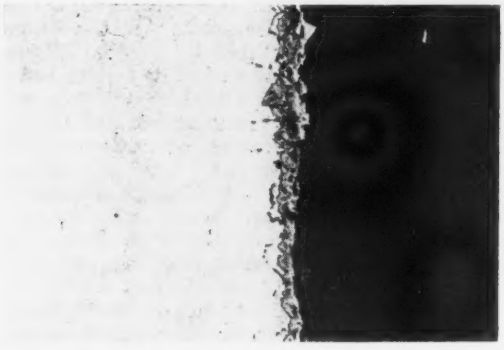


Fig. 7—15% CO_2 + 1% CO + 84% N_2, 120 min: adherent oxide × 200

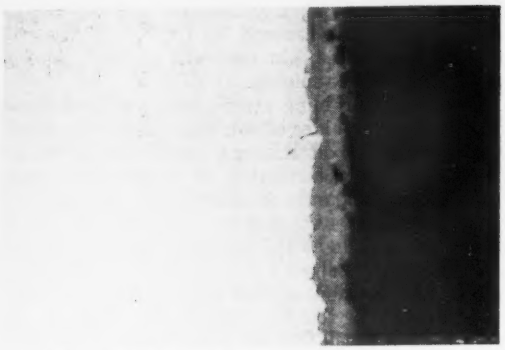


Fig. 8—O_2, 30 min: thin adherent oxide × 2000

EXPERIMENTAL RESULTS

The oxygen picked up during the oxidation process was determined by weighing the specimens before and after heating in the respective atmospheres. The increases in weight were converted to grammes of oxygen picked up per square metre surface of specimen and were plotted graphically against the oxidation time or other suitable variable. There is a fairly considerable spread in the experimental values.

Figures 3 and 4 illustrate the oxidation rates in some different types of furnace atmosphere. If the gas is free of sulphur, the oxidation rate, as might be expected, is higher in a mixture containing demonstrable quantities of O_2 (hereafter sometimes called an oxidizing atmosphere) than in a mixture with excess of CO (hereafter sometimes called a reducing atmosphere). It should perhaps be pointed out that it is of

Fig. 9—O_2, 60 min: start of flaking × 600

Table II
RESULTS OF X-RAY STUDIES
Investigation conducted by Nils-Åke Hovgard

No.	Oxidation Data	Visual Examination	Radiation	Type of Specimen	Phases			Remarks
					Certain	Probable	Possible	
1	17% CO_2, 1% O_2, 82% N_2, 1050° C, 120 min	Grey flaking outer layer	Fe	Scraped-off oxide	Fe_2O_3, spinel (Fe-rich)		FeO	Lattice parameter of spinel 8·37 kx; chem. analysis of film showed Cr content 6·2%
2	17% CO_2, 1% O_2, 82% N_2, 1050° C, 120 min	Dark adherent lower layer	Fe	Sheet strip, outer oxide layer scraped off	Spinel (Fe-rich)	Fe_3O_4, martensite		
3	1000% O_2, 1050° C, 5 h	Grey flaky oxide	Fe	Scraped-off oxide	Fe_2O_3, spinel (Fe-rich)			
4	17% CO_2, 2% O_2, 0·1% SO_2, 80·9% N_2, 1050° C, 5 min	Green adherent oxide	Cu	Sheet strip	Cr_2O_3, γ–Fe, martensite	Spinel (Cr-rich)		
5	16·4% CO_2, 2% O_2, 0·1% SO_2, 81·5% N_2, 1050° C, 10 min	Dark adherent oxide (surface layer partly scraped off)	Fe	Sheet strip	Fe_2O_3, γ–Fe, $(FeCr)_{23}C_6$	Spinel $(Fe, Cr)_3O_4$		
6	16·3% Co_2, 1·2% O_2, 0·1% SO_2, 82·4% N_2, 1050° C, 15 min	Dark grey somewhat flaky oxide	Fe	Sheet strip	$(FeCr)_2O_3$, spinel γ–Fe, martensite, $(FeCr)_{23}C_6$,			
7	16·5% CO_2, 1·4% O_2, 0·1% SO_2, 82% N_2, 1050° C, 15 min	Green adherent oxide	Fe	Sheet strip	$(FeCr)_2O_3$, (Cr-rich), γ–Fe, martensite, $(FeCr)_{23}C_6$		SiO_2	Diversely oxidized specimen: least oxidized portion
8	16·5% CO_2, 1·4% O_2, 0·1% SO_2, 82% N_2, 1050° C, 15 min	Dark adherent oxide	Fe	Sheet strip	$(FeCr)_2O_3$, γ–Fe, martensite, $(FeCr)_{23}C_6$		Spinel	Ditto: centre layer
9	16·5% CO_2, 1·4% O_2, 0·1% SO_2, 82% N_2, 1050° C, 15 min	Grey adherent oxide	Fe	Sheet strip	$(FeCr)_2O_3$, spinel (Fe-rich), martensite, $(FeCr)_{23}C_6$			Ditto: most oxidized portion
10	15·2% CO_2, 1·2% O_2, 0·1% SO_2, 83·5% N_2, 1050° C, 30 min	Grey adherent oxide (powdery surface)	Fe	Sheet strip	Fe_2O_3, γ–Fe, $(FeCr)_{23}C_6$	Spinel		No chemically observed sulphur (< 0·005% S)
11	16·4% CO_2, 1·3% CO, 82·8% N_2, 1050° C, 15 min	Dark adherent oxide	Fe	Sheet strip	spinel (Cr-rich), FeO, γ–Fe, martensite, $(FeCr)_{23}C_6$			
12	16% CO_2, 0·7% CO, 83·3% N_2, 1050° C, 120 min	Dark oxide, incipient flaking	Cu	Sheet strip	spinel (Cr-rich), FeO, γ–Fe, martensite, $(FeCr)_{23}C_6$		$(FeCr)_2O_3$	
13	15% CO_2, 1% CO, 0·1% SO_2, 83·9% N_2, 1050° C, 1 min	Greenish adherent oxide	Cu	Sheet strip	Cr_2O_3, γ–Fe, $(FeCr)_{23}C_6$	Spinel	Martensite	
14	15·4% CO_2, 2·1% CO, 0·1% SO_2, 82·4% N_2, 1050° C, 10 min	Dark adherent oxide	Cu	Sheet strip	$(FeCr)_2O_3$, spinel (Cr-rich), martensite		FeO, MnO, FeS, CrS, Ni_3S_2, MnS, $(NiFe)_9S_8$, C	Chemical analysis of oxide film showed sulphur content 0·07%
15	16% CO_2, 2% CO, 0·1% SO_2, 81·9% N_2, 1050° C, 60 min	Dark flaky oxide	Fe	Scraped-off oxide	Spinel, FeO, martensite	γ–Fe	FeS, Ni_3S_2, Ni	Chemical analysis of oxide film showed Cr 13·9%, S 1·1%
16	10·2% CO_2, 2·3 O_2, 8·8% H_2O, 0·5% SO_2, + 78·2% N_2, 10 min	Grey flaky surface layer	Fe	Sheet strip, outer oxide layer scraped off	Fe_2O_3, spinel, FeO, γ–Fe martensite	$(FeCr)_{23}C_6$		
17	14·1% CO_2, 1·9% O_2, 12% H_2O, 0·1% SO_2, 71·9% N_2, 1050° C, 30 min	Dark adherent lower layer	Fe	Sheet strip	$(FeCr)_2O_3$, spinel	$(FeCr)_{23}C_6$		Portion where flaking taken place
18	8·4% CO_2, 5·1% CO, 5·4% H_2O, 1·8% H_2, 0·3% SO_2, 79% N_2, 1050° C, 30 min	Dark grey heavy crystalline oxide	Fe	Sheet strip	FeO, spinel (Cr-rich)			
19	In reheating furnace 900–1100° C for 90 min, fuel oil No. 2	Severe flaking	Fe	Scraped-off oxide	Fe_2O_3, spinel		FeS, CrS, MnS, FeS.Cr:S	
20	Humid air, 1000° C, 12 days	Grey flaky oxide	Fe	Scraped-off oxide	Fe_2O_3, spinel			Chemical analysis of oxide showed Cr 6·0%

Note: After preparing the paper, the author has become aware of two papers giving a very comprehensive X-ray study of scaling of Cr and Ni–Cr steels by Yearian *et al.* (*Corrosion*), 1956, vol. 12, pp. 515–525 and 561–568).

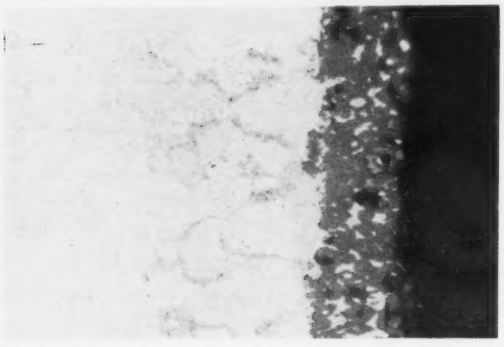


Fig. 10—15% CO_2 + 2·1% CO + 0·1% SO_2 + 83% N_2, 10 min: ' sulphur penetration ' × 800

course improper, as is done here, to call an atmosphere reducing because it contains CO in a quantity that is demonstrable by means of Orsat's gas analysis apparatus. 18–8 steel can, in fact, be oxidized in such an atmosphere. This mode of expression has been chosen, however, so that the designations of atmospheres shall not be too cumbersome, and they do conform with ordinarily accepted parlance.

Oxide films are formed in different ways according to the type of atmosphere. The difference is even noticeable on visual examination. Excess of oxygen produces a powdery, light-grey surface, while excess of CO produces adherent black or greenish films. The latter are extremely thin even after 30 min of oxidation (Fig. 5). The former are thicker after the same oxidizing time, and under the microscope are clearly shown to consist of at least two layers of oxide (Fig. 6). The outer oxide phase readily flakes off and gives rise to the powdery surface. Another characteristic of oxidation in a gas with oxygen excess is that the fairly slow initial oxidation suddenly accelerates, being followed by a rapid process under heavy scaling. This does not occur with excess CO in the gas (Fig. 4). After 120 min of oxidation, CO-containing gas still produces thin and adherent films (Fig. 7), whereas 120 min in a mixture of O_2, CO_2, and N_2, or in CO_2 and N_2, produces thick flaking layers. Oxidation in pure

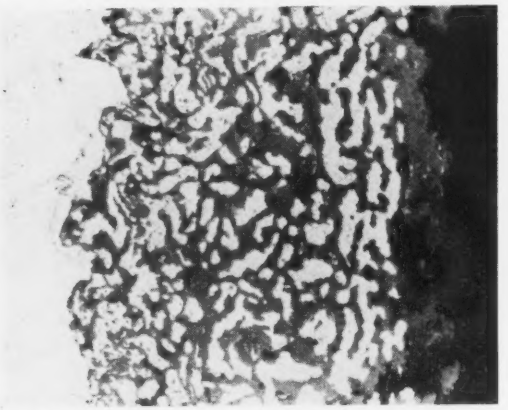


Fig. 11—14% CO_2 + 1·3% CO + 0·1% SO_2 + 85% N_2, 30 min: ' sulphur penetration ', heavy destruction of specimen × 600

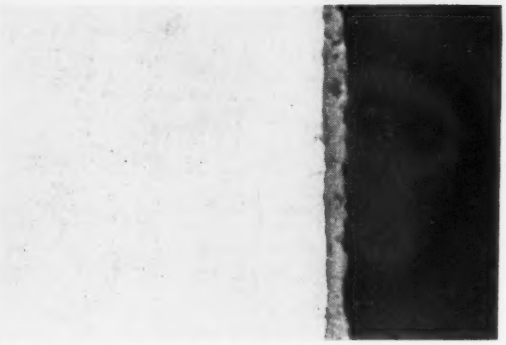


Fig. 12—16% CO_2 + 2·7% O_2 + 0·1% SO_2 + 81% N_2, 5 min: thin adherent oxide. No influence from sulphur with O_2 excess in the gas × 600

oxygen produces the same types of scale as in CO_2, O_2, N_2 mixtures (Figs. 8 and 9).

Microstudies with polarized light showed that the outer light-grey flaky film in Figs. 8, 9, and 10 is anisotropic, which, together with the colour, makes it probable that the film consists of pure Fe_2O_3 or a solid solution of sesquioxide, $(Fe, Cr)_2O_3$. The main bulk of the better adhering oxide underneath this film is, on the other hand, isotropic. The structure of the inner layer will be dealt with in greater detail in the subsequent discussion on the oxidation mechanism for 18–8 steel.

To study the oxide constituents further, a series of X-ray diffraction studies were made, the results of which are given in Table II. By direct irradiation on the surfaces of oxidized specimens it was confirmed that the grey surface oxide formed in gas with excess of O_2 was practically pure Fe_2O_3. Thicker oxide films that are formed during and after the acceleration of the oxidation process can be scraped off the specimen; powder analyses indicated that this type of oxide scale consists of Fe_2O_3 and Fe_3O_4. The chromium content in the scraped off powder was found by chemical analysis to be about 6%. With excess of CO in the oxidation gases the outer light-grey layer is lacking, as the microphotographs show (Figs. 5 and 7). Under the microscope there are only isotropic blue-grey films which were shown by X-rays to consist of spinel phase and wüstite.

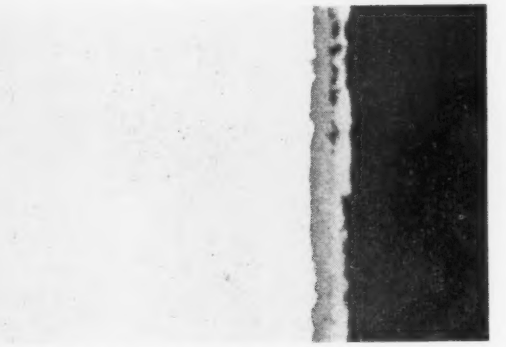
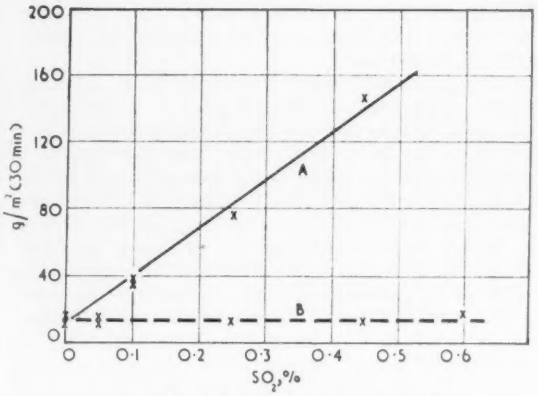


Fig. 13—15% CO_2 + 1·0% O_2 + 0·25% SO_2 + 84% N_2, 30 min: no influence from sulphur × 600



A. 15% CO_2, 1·5% CO, 83% N_2, varying SO_2
B. 16% CO_2, 1·5% O_2, 82% N_2, varying SO_2
Material: *S3* Temp.: 1050° C.

Fig. 14—Influence of SO_2 addition on oxidation result in 'oxidizing' and 'reducing' atmospheres

The above applies to sulphur-free atmospheres. If SO_2 is added, the oxidation result changes most strikingly in a '*reducing*' atmosphere. The oxygen uptake now proceeds extremely rapidly as shown in Fig. 3. In an '*oxidizing*' atmosphere, on the other hand, addition of SO_2 has very little effect and the oxidation rate decreases rather than increases.

The change in oxidation rate consequent on the addition of sulphur to *CO-containing* gas is accompanied by a total change in the scale structure. The oxide scale is not sharply delimited, but starts to form in this case by penetrating along the grain boundaries of the metal, resulting in a subscale (Figs. 10 and 11). Only in the outermost portions has complete oxidation taken place, for which reason most of the oxide scale consists of a mixture of oxide and metal. This form of scale is typical of oxidation in a gas containing sulphur and carbon monoxide. The scale adheres to the metal and does not flake off until it attains a considerable thickness.

In a reducing atmosphere the surface of the specimen is not only attacked by sulphur and oxygen, but is also carburized. As mentioned above, the oxidation rate is not appreciably affected by the addition of SO_2 to an *O_2-containing* gas. Nor is there any noticeable change in the structure of the oxide layers, which is the same as in the absence of sulphur. Figures 12 and 13 show oxide films formed in sulphur-containing gas, but could equally well illustrate oxidation in a sulphur-free atmosphere.

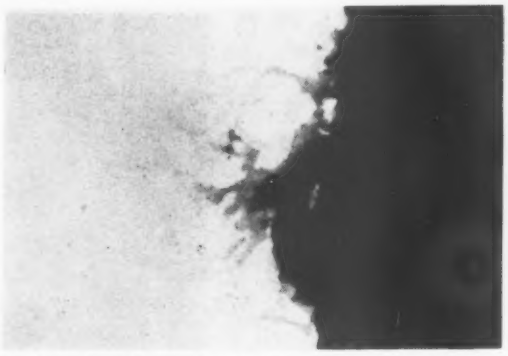


Fig. 16—5% CO_2 + 14·4% CO + 0·1% SO_2, 30 min: 'sulphur penetration' at surface defect × 600

Figure 14 shows the striking difference in the influence of SO_2 addition on oxidation rate in a slightly 'oxidizing' and in a slightly 'reducing' atmosphere. In a gas containing 1·5% O_2 the oxidation rate is practically independent of the SO_2 content. For the same content of CO, on the other hand, the oxygen uptake is directly proportional to the SO_2 addition.

Increasing the O_2 content from 1·5% to 6% caused no distinct change in the oxidation result at a SO_2 content of 0·1%. As soon as there is any O_2 excess, the oxidation is not appreciably affected by the oxygen or sulphur content.

By greatly increasing the CO content, the formation of scale can be diminished both in sulphur-free and sulphur-containing 'reducing' atmospheres. Thus, at 14% CO, 2% CO_2, and 0·1% SO_2 added, the SO_2 addition has lost its promoting effect on scaling and the oxide film is thin and adherent (Fig. 15). But there is a tendency to intercrystalline attack under formation of a subscale, especially at defects in the surface of the steel (Fig. 16). Also, in the case of sulphur-containing atmospheres, the phase structure

Fig. 15—5% CO_2 + 14·4% CO + 0·1% SO_2 + 81% N_2, 30 min: thin adherent oxide. High CO content counteracts the oxidation-promotion effect of the sulphur × 1000

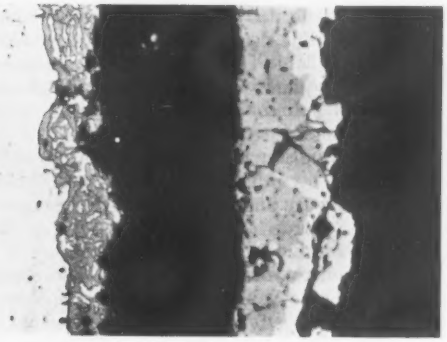


Fig. 17—16% CO_2 + 1·6% CO + 0·1% SO_2 + 82% N_2, 15 min: thereafter 16% CO_2 + 1·8% O_2 + 0·1% SO_2, also 15 min: flaking oxide × 300

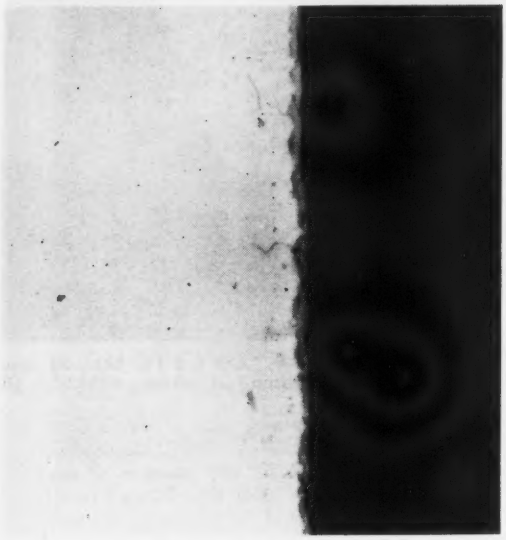


Fig. 18—16% CO_2 + 1·8% O_2 + 0·1% SO_2 + 82% N_2, 15 min; thereafter 16% CO_2 + 1% CO + 0·1% SO_2 + 83% N_2, also 15 min: thin adherent oxide × 1000

of the oxide film has been studied by X-ray methods (cf. Table II).

Studies were made of oxide films formed by oxidation with a gas of type 16% CO_2, 1% CO, 0·1% SO_2, remainder N_2. Spinel, wüstite, austenite, nickel, and Fe and Ni sulphide phases were found. The latter result, as well as microscopic studies in polarized light and studies of etching reactions based on a diagram taken from *Metals Handbook*,[27] showed that the penetration along the grain boundaries of the austenite, when oxidized in a sulphur-containing, moderately reducing gas, takes place under formation of sulphides or oxide sulphides and that the outer scale consists of wüstite and a mixture of spinel and metal phases. Of the sulphides, FeS, which is anisotropic and has a characteristic mustard-yellow colour, can be directly identified under the microscope.

X-ray diffraction studies of oxide scales formed in a sulphur-containing gas with a few percent excess of oxygen confirmed the findings of the microscopic studies that sulphides are not formed in an ' oxidizing ' atmosphere (Table II: 4–10). In the discussion that follows, an explanation will be given of the differing influence of sulphur in ' oxidizing ' and ' reducing ' types of atmosphere.

So far oxidation in gaseous mixtures without H_2 and H_2O has been discussed. Considerable quantities of these gases are formed, however, during combustion of an oil. Some additional tests were, therefore, made to examine what effect the *presence of H_2 and H_2O* have on the oxidation result. The composition of the oxidizing gases was made to conform closely with the combustion gases from a normal fuel oil No. 2 (*see* Table V). As shown by Table III, the oxidation processes in the different types of atmosphere, ' reducing ' and ' oxidizing ' are essentially similar, whether H_2O and H_2 are present or not. Microstudies have shown that the oxidation structures are largely the same, only the amount of wüstite phase is increased.

Statements have been encountered in the literature to the effect that a *change in the type of atmosphere* during oxidation causes a high increase in the rate of oxidation for 18–8 steel. Some tests were made to check this. It was found that a change from 'reducing' (1·6% CO, 0·1% SO_2) to ' oxidizing ' gas (1·8% O_2, 0·1% SO_2) produced violent scaling (Fig. 17), whereas a change from ' oxidizing ' to ' reducing ' gas produced an adherent oxide (Fig. 18). The protection afforded by pre-oxidation in excess of O_2 is, however, not maintained during lengthy subsequent treatment in an atmosphere containing both CO and SO_2. As an example it may be mentioned that heavy scaling occurred after 15 min in an ' oxidizing ', followed by 105 min in a ' reducing ' atmosphere.

As regards the test results, moreover, it may be mentioned that the two 18–8 steels examined behaved very similarly during the oxidation processes. The Sandviken steel 2*R*2*N*10 (cf. Table I), however, constantly oxidized rather more quickly than 0*R*2*N*10. Differences of surface finish, therefore, had a greater influence on the result of oxidation than the small difference in composition between these grades of steel. In the oxidation of steel *S*2, which had a ground scratched surface, a flaky oxide was formed after a shorter time than with the practically scratch-free cold-rolled steels *S*1, *S*3, and *S*5.

THE OXIDATION MECHANISM FOR 18–8 STEEL AT 1050° C

The transition from a slowly growing adherent oxide film to a rapidly growing flaky oxide film—the ' breakthrough ' that occurs on oxidation of an 18–8 steel in an atmosphere with excess of oxygen—has

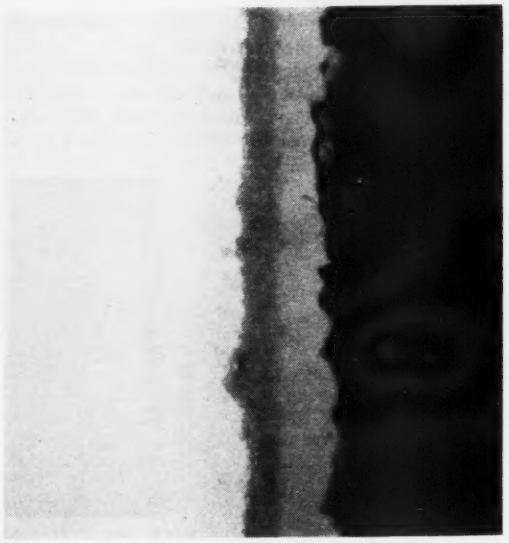


Fig. 19—16% CO_2 + 2·7% O_2 + 0·1% SO_2 + 81% N_2, 5 min: incipient attack on sesquioxide. Multi-phase inner layer × 2000

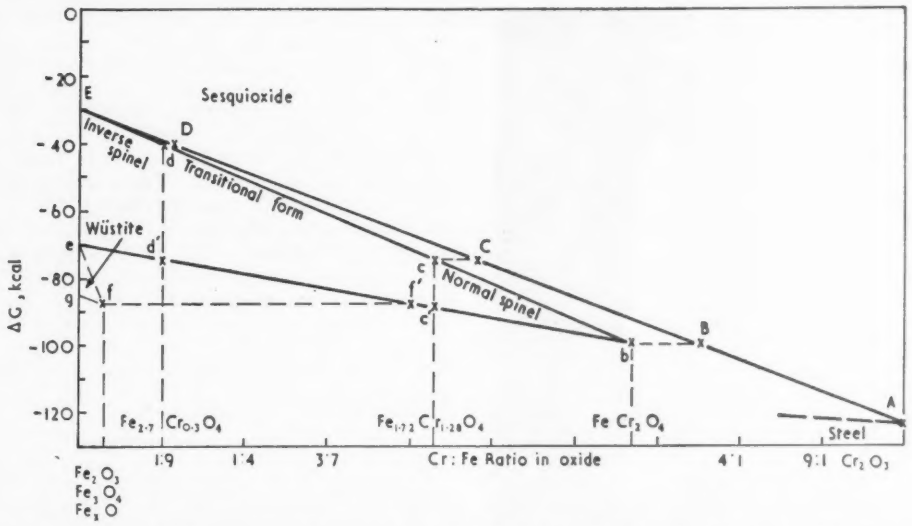


Fig. 20—Reduction of Fe–Cr sesquioxides to spinels at 1050° C: hypothetical phase diagram. When the oxygen potential for chromium oxide has risen above point *B* as a result of dissolution of iron, the spinel phase (chromite) has a lower oxygen potential than the iron-containing chromium oxide. Spinel is therefore formed in contact with the steel. The iron content of the spinel is, however, higher than that of the sesquioxide so that the latter is enriched in chromium and the continued formation of oxide is retarded

been the subject of a number of laboratory studies. All these studies indicate that the discontinuity in the oxidation process is due to local ' break-through ' of a protective oxide film, after which a rapid oxidation takes place under formation of iron-rich scaling oxides.[8, 28, 29] The ' breakthrough ' is attributed either to mechanical rupture of a chromite layer after it has achieved a given critical thickness[8] or to chemical breakdown of a chromium oxide layer when the metal surface has been sufficiently depleted in chromium by the formation of chromium oxide.[28, 29]

Fig. 21—15% CO_2 + 1% O_2 + 0·25% SO_2, 30 min: incipient ' breakthrough ', causing sesquioxide to start reducing to Fe-rich spinel × 2000

The observations made in the present study support the following interpretation of the events occurring during oxidation of 18–8 steel at 1050° C.

In an atmosphere with excess of oxygen an oxide film is first formed which has the green colour, and displays the X-ray pattern, of Cr_2O_3 (Table II: 4). As would be expected, the first oxide to be formed is that of the metal having the greatest affinity to oxygen. This green oxide film, however, only lasts for a minute or so. The surface thereafter turns light-grey, and microscopic and X-ray examination indicates that the film now contains several phases. It consists of an outer single-phase, anisotropic layer of $(Fe, Cr)_2O_3$ and of an inner *multiphase* layer containing $(Fe, Cr)_2O_3$ and spinel and perhaps also metallic particles (Fig. 19 and Table II : 5, 6). This oxide film is still protective and the ' breakthrough ' does not occur until more than 30 min after the film has reached the multiphase stage.

After the ' breakthrough ' the oxidation proceeds to virtually pure iron oxides (Fig. 23 and Table II : 1, 2). Iron oxides, as is well known, provide little protection against oxidation. It might perhaps be expected that Fe_2O_3 layers, through which the rates of diffusion are low,[22, 30] would afford protection to iron and iron alloys. Fe_2O_3, however, is prevented from growing into thick protective layers owing to the fact that the inner surface of the oxide is *reduced* to lower iron oxides in accordance with the schematic formulæ

$$Fe + 4Fe_2O_3 \rightarrow 3Fe_3O_4$$
$$Fe + Fe_3O_4 \rightarrow 4FeO$$

The magnetite and wüstite, which have high rates of diffusion, grow rapidly in thickness and are soon broken down as a result of the occurrence of internal stresses and diffusion porosities.[31] The failure normally occurs in the magnetite layer.[31, 32]

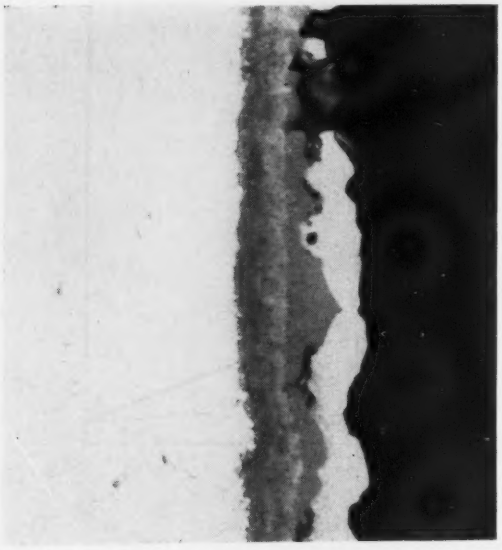


Fig. 22—As Fig. 21, but more oxidized portion. Coherent Fe-rich spinel layer × 2000

To illustrate further the process of oxide formation on 18–8 steel in gas containing O_2, the following experiment was made. A sheet strip specimen was exposed to a gas containing about 1% O_2 so that one end of the specimen was oxidized substantially more than the other. The least oxidized end of the specimen became covered with a thin green layer of chromium oxide, the centre was dark, indicating a spinel phase, and the most oxidized end was covered with what might be judged to be light-grey Fe_2O_3-rich sesquioxide. X-ray diffraction studies confirmed the visual observation of the phase sequence (Table II: 7–9).

The oxidation of 18–8 steel thus starts at 1050° C in an oxygen-rich atmosphere by the formation of a Cr_2O_3 film. The rate of diffusion for Cr and Fe in the metal appears, however, to be too slow to cover the loss of chromium in the surface layer, so that the metallic phase adjoining the oxide film is soon impoverished in chromium and the Cr_2O_3 layer can be attacked from within by reaction with the steel under formation of primarily a solid solution $(Fe, Cr)_2O_3$. The oxygen potential in this phase increases on the dissolution of iron. At a certain Fe content the phase is unstable close to the steel, but its content of trivalent iron can be reduced, whereupon spinel forms and the oxide film becomes multiphase. But there is still a satisfactory protection for the metal surface, i.e. the rate of oxidation is slow.

The oxygen potentials of some oxides as functions of the temperature were recorded in Fig. 1. To illustrate the oxygen potentials for iron–chromium oxides at 1050° C and different ratios of Fe: Cr in the oxides, Fig. 20 has been drawn. Owing to the scanty data on these oxides in the literature the diagram, which may be conceived of as a kind of phase diagram for Fe–Cr oxides at 1050° C, is subject to a number of schematic assumptions. Thus the oxygen potential of the sesquioxide has been assumed to rise linearly from chromium oxide to hematite (line *AE*) and the limits of the spinel oxygen potentials likewise in a straight line from chromite to the oxygen potentials of the magnetite in equilibrium with Fe_2O_3 or wüstite, (lines *bE* and *be* respectively). As regards the solubility of the wüstite for Cr, no data have been found in the literature and the lines *fe* and *fg* are entirely hypothetical, the data for pure iron oxide (points *e* and *g*) alone being known. Under these assumptions the region *Ebe* is the region of existence of the spinel, i.e. it represents the Fe–Cr compositions and the oxygen potentials at which Fe, Cr spinels can exist. The region *efg* is similarly the hypothetical region of existence of the wüstite. At potentials above line *AE* the sesquioxide alone is stable. It should perhaps be pointed out that the diagram is based on the Fe: Cr ratio in the oxides. The composition of the metal in equilibrium with different oxides, however, cannot be read from this diagram.

The diagram will now be employed for schematic interpretation of the process involved in the oxidation of 18–8 steel in *oxygen-rich gas*. The reasoning properly applies to pure Fe–Cr alloys, but the nickel content in 18–8 steel is considered to have so small an influence on the salient features of the diagram that the same reasoning may be directly employed for this steel. When Fe is dissolved in the chromium oxide formed on incipient oxidation, the oxygen potential increases at the inner surface of the oxide along line *AE*. After passing point *B*, the formation of spinel mentioned above takes place. The oxygen potential of the spinel will hereafter lie below that of the sesquioxide, and the spinel, primarily chromite, will be stable in contact with the steel. But since the Fe: Cr ratio in the spinel is higher than in the sesquioxide at the same oxygen potential, the formation of spinel must be accompanied by an enrichment of Cr in the sesquioxide. The oxygen potential in this oxide thereby falls towards point *B* and the forma-

Fig. 23—17% CO_2 + 2% O_2 + 0·1% SO_2 + 81% N_2, 120 min: after the 'breakthrough'. Flaking iron oxides × 1000

Table III

OXIDATION OF 18–8 STEEL AT 1050° C IN HUMID GASES

Synthetic gases containing H_2 and H_2O in roughly the same proportions as combustion gas from fuel oil No. 2

Oxidation Time, min	Gas Composition, %						SO_2 Addition, %	Weight Increase, g m²	Remarks
	CO_2	CO	H_2O	H_2	O_2	N_2			
5	13·1	3·2	9·9	1·3	..	72·5	..	4	C deposition from gas
5	9·0	2·1	6·8	0·9	..	81·1	0·1	11	
15	14·9	..	12·7	..	1·0	71·4	..	5	
15	13·4	..	11·4	..	3·4	71·7	0·1	3	
15	11·8	1·0	9·5	0·5	..	77·2	..	4	C deposition from gas
15	8·7	1·9	6·6	0·8	..	81·9	0·1	31	
30	16·7	..	14·2	..	1·5	67·6	..	7	
30	14·1	..	12·0	..	1·9	71·9	0·1	6	
30	10·1	1·3	7·6	0·5	..	81·5	..	8	Strong C deposition
30	9·2	1·8	7·0	0·8	..	81·1	0·1	135	

tion of spinel is retarded. The retardation is, however, only temporary.

As stated, the rates of diffusion through spinel high in Cr and through sesquioxide are slow, and for a time the oxide film grows gradually thicker under formation of an inner, mixed spinel–sesquioxide layer (Fig. 19). The case is different when the sesquioxide has become rich in iron and is reduced to iron-rich spinel. In the first place the diffusion of cations through the iron-rich spinel proceeds much more quickly than through the chromium-rich spinel; in the second place the chromium enrichment in the sesquioxide, with its arresting effect on the reaction, is lessened the richer in iron this oxide becomes—at Fe_2O_3 there is a direct transition to Fe_3O_4. Both factors contribute to successively more rapid formation of increasingly iron-rich oxides, which soon scale off the metal surface, as happens in oxidation of pure iron. The process is illustrated in Figs. 21, 22, and 23: Fig. 21 shows the start of the ' breakthrough ' when the sesquioxide begins to be reduced to larger portions of spinel, which in time more and more acquire the characteristic red-grey colour of magnetite. The spinel grows into a coherent layer (Fig. 22) and gradually the outer parts of the oxide flake off (Fig. 23).

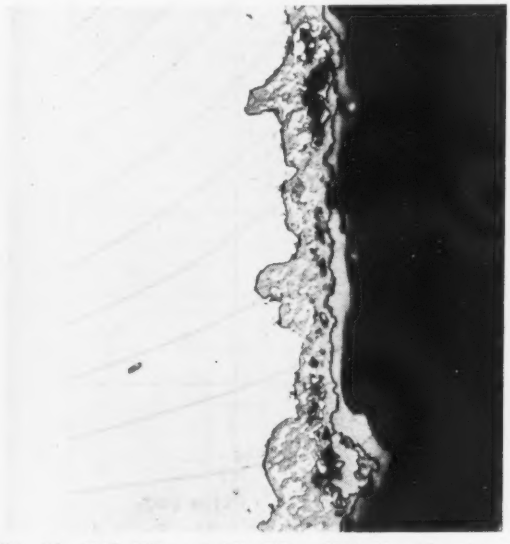


Fig. 24—16% CO_2 + 1·3% CO + 83% N_2, 15 min: a reducing atmosphere produces after some time the phase sequence: steel, spinel, wüstite. The spinel layer contains unoxidized portions of metal and probably also sesquioxide

The phase sequence in the oxide film, shown in Fig. 22 (sesquioxide on the outside, thereafter iron-rich spinel, and on the inside a mixture of spinel and chromium-rich sesquioxide) has been confirmed by the X-ray studies (Table II: 5). To establish the composition of the spinel unequivocally by determination of the lattice parameters alone is, however, impossible since the lattice parameters of the Fe, Cr spinels are not a simple function of the spinel's contents of Fe or Cr.[16] This is because the value of a lattice parameter may represent several compositions of the spinel, conforming with both normal and inverse structures. To obtain unequivocal results, determinations of lattice parameters must be supplemented by chemical analyses, which are extremely difficult with the thin films in question. In addition to iron and chromium, the spinel may also contain Ni, Mn, etc., as mentioned earlier.

If the oxygen potential in the inner layer of the oxide scale lies above point *f* in Fig. 21, a wüstite phase may be formed from spinel by the same mechanism as has been proposed for the formation of spinel from sesquioxide. When oxidizing with oxygen excess, however, wüstite phase has only been definitely demonstrated in the oxide scale in one case (Table III : 16). The oxidation had taken place with humid gas and the oxide attack had been comparatively severe. The quantity of wüstite was, however, very small. Moreau[33-35] has stated that, after oxidation of an 18% chromium steel in air, the majority of the oxide scale consists of a matrix of wüstite in which the spinel phase is dispersed. This type of scale has not been encountered in the present investigation. Moreau, however, employed very long oxidation times and his structures might refer to conditions long after the ' breakthrough ' of the protective film.

Oxidation with a *CO-containing, sulphur-free gas* proceeds slowly and no acceleration takes place, at least not in an oxidizing time of 2 h, as shown in Fig. 4. The process appears initially to conform with that caused by an excess of O_2. Here, too, in the first stage of oxidation a green chromium oxide layer is formed which soon darkens under Fe enrich-

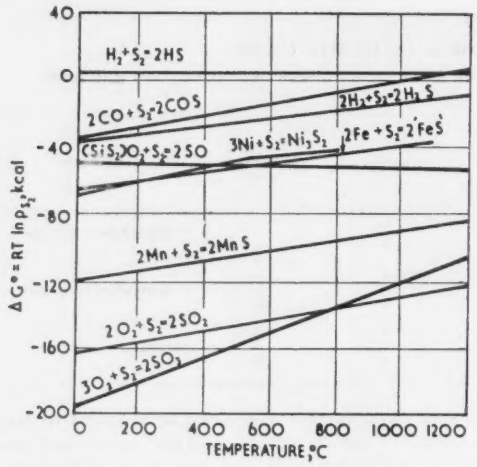


Fig. 25—Sulphur potential diagram

ment and formation of spinel, accompanied by a slow growth of the oxide layer. With CO excess, however, the oxygen potential is so low that the Fe enrichment in the sesquioxide and the Fe content in the spinel are moderate and below the values at which the oxidation process becomes accelerated. This is because, when the Fe content in the sesquioxide has become so large that the oxygen potential for this oxide on further Fe enrichment would exceed the oxygen potential in the atmosphere, the conditions for new formation of sesquioxide have disappeared and this oxide phase will be entirely consumed. The iron which diffuses out through the spinel may instead be oxidized to wüstite! Wüstite in fact becomes the oxide phase which, within the limits imposed by the oxygen potential of the gas, can have a higher Fe content than the spinel. In a reducing atmosphere, therefore, at least at oxygen potentials between *e* and *ff'* in Fig. 20, the phase sequence will after some time be wüstite, spinel, steel. This is confirmed by etching and microscopic examination of the resulting surface film (Fig. 24). The wüstite has also been clearly demonstrated by X-ray (Table II: 11, 12).

In the investigation of the lattice parameters of the Fe–Cr spinels by Yearian, Kortright, and Langenheim,[16] some observations were made which support the mechanism of oxide formation on 18–8 steel proposed by the present author, involving the formation of spinel under enrichment of chromium in the sesquioxide. Spinels for lattice-parameter determinations were prepared through reduction of Fe, Cr sesquioxides with different iron and chromium contents. It was found that the end of the reaction proceeded very slowly and that it had a tendency to stop before all sesquioxide was converted into spinel. There was, in fact, a constant increase in the chromium content in the still unreduced material, so that the final reduction to spinel involved the reduction of a sesquioxide that was very rich in chromium and therefore averse to reaction. The investigation also comprised partial oxidations of spinel to sesquioxide, the oxidation products being oxygen-rich spinel and a sesquioxide solution with a higher Cr: Fe ratio than that of the spinel.

INFLUENCE OF SULPHUR ON THE OXIDATION PROCESS

As is apparent from the results of the experiments, the addition of SO_2 to the atmosphere has decidedly different effects on scaling under conditions of O_2 excess and CO excess. This has also been repeatedly stated in the literature (e.g. Scheurer[36] and Preece[37]). The difference in the structure of the scale after oxidation in the different types of atmosphere is so striking that it can hardly be ascribed to a kinetic effect, such as 'breakthrough' of the protective Cr_2O_3 layer formed in oxidizing atmosphere, but must rather be due to differences in the equilibrium structure of the oxide film: i.e. phases are formed in one case which cannot be formed in the other. Some thermodynamic calculations were therefore made to discover what equilibrium phases can be formed in different types of sulphur-containing atmosphere.

The influence of sulphur on the structure of the scale can be attributed to the formation of sulphide or oxysulphide.[36–39] Whether a sulphide can be formed on a metal surface or not is dependent on the partial pressure of the sulphur vapour above the surface. Every sulphide is at a certain temperature in equilibrium with a certain sulphur pressure. In the same way as oxygen potential diagrams may be plotted for metal–oxygen systems, sulphur potential diagrams may be plotted for metal–sulphur systems. A sulphur potential diagram has been drawn for the solid and gaseous sulphide compounds of interest here (Fig. 25). At a sulphur potential above the equilibrium line for a certain sulphide, this may be newly

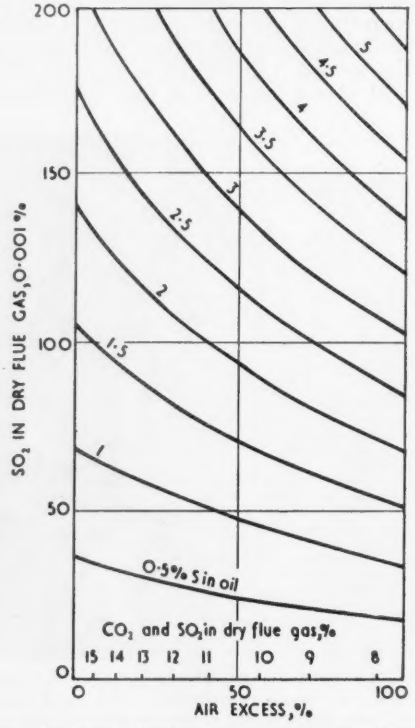


Fig. 26—Sulphur dioxide content in flue gases from fuel oil[43]

Table IV

PRESENCE OF SULPHUR IN GASEOUS ATMOSPHERES WITH DIFFERENT CO CONTENTS

Sum of CO + CO_2 = 16%, remainder of gas N_2 and sulphurous constituents; total sulphur corresponds to 0·1% addition of SO_2

CO, %	CO_2, %	p_{S_2}, atm	S_2, %	p_{COS}, atm	COS, %	p_{SO_2}, atm	SO_2, %
0	16	$0·68 \times 10^{-16}$	$0·68 \times 10^{-14}$	$0·31 \times 10^{-13}$	$0·31 \times 10^{-11}$	$0·10 \times 10^{-2}$	0 ·10
1	15	$0·52 \times 10^{-8}$	$0·52 \times 10^{-6}$	$0·11 \times 10^{-4}$	$0·11 \times 10^{-2}$	$0·98 \times 10^{-2}$	$0·98 \times 10^{-1}$
2	14	$0·70 \times 10^{-6}$	$0·70 \times 10^{-4}$	$0·82 \times 10^{-4}$	$0·82 \times 10^{-2}$	$0·78 \times 10^{-2}$	$0·78 \times 10^{-1}$
4	12	$0·23 \times 10^{-5}$	$0·23 \times 10^{-3}$	$0·30 \times 10^{-3}$	$0·30 \times 10^{-1}$	$0·26 \times 10^{-2}$	$0·26 \times 10^{-1}$
6	10	$0·23 \times 10^{-5}$	$0·23 \times 10^{-3}$	$0·45 \times 10^{-3}$	$0·45 \times 10^{-1}$	$0·80 \times 10^{-2}$	$0·80 \times 10^{-1}$
10	6	$0·17 \times 10^{-5}$	$0·17 \times 10^{-3}$	$0·64 \times 10^{-3}$	$0·64 \times 10^{-1}$	$0·90 \times 10^{-2}$	$0·90 \times 10^{-2}$
15	1	$0·11 \times 10^{-5}$	$0·11 \times 10^{-3}$	$0·78 \times 10^{-3}$	$0·78 \times 10^{-1}$	$0·17 \times 10^{-2}$	$0·17 \times 10^{-1}$

formed or growing. The data used in the diagram are taken from Richardson and Jeffes.[40] Unfortunately neither this paper nor later publications on thermodynamic data[41, 42] contain values for Cr sulphides. The equilibrium lines of these sulphides may, however, be assumed to lie between those of FeS and MnS.

A number of calculations of sulphur partial pressures in various types of gaseous atmosphere, as also of the partial pressures of other gases, have been made on the basis of the gas analyses performed during the oxidation experiments. The method of making the calculations will be indicated schematically.

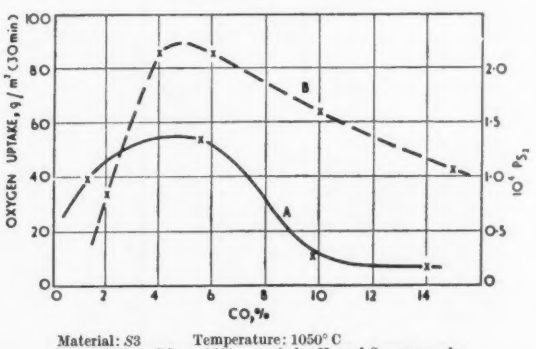
It is assumed that the composition of the gas is 1% O_2, 15% CO_2, remainder N_2 and S compounds. The sulphur potential diagram (Fig. 25) shows immediately that SO_2 is the most stable of the sulphur compounds that can be formed at 1050° C, whereas SO_3, SO, and COS have higher sulphur potentials. The following equilibrium equations may be set up. The equilibrium constants have been calculated from the ΔG° values given by Richardson and Jeffes.[40] The formation of CS_2 and CS has not been taken into consideration.

$$\frac{p^2_{SO_2}}{p^2_{O_2} \cdot p_{S_2}} = 10^{21} \quad \text{.....(6)}$$

$$\frac{p^2_{SO_3}}{p^3_{O_2} \cdot p_{S_2}} = 1·6 \times 10^{19} \quad \text{.....(7)}$$

$$\frac{p^2_{SO}}{p_{O_2} \cdot p_{S_2}} = 4·5 \times 10^{8} \quad \text{.....(8)}$$

$$\frac{p^2_{COS}}{p^2_{CO} \cdot p_{S_2}} = 0·24 \quad \text{.....(9)}$$



Material: *S*3 Temperature: 1050° C
Sum of CO + CO_2 = 16%, remainder N_2 and S compounds.
The total sulphur represented by 0·1% addition of SO_2.
A. Oxygen uptake (g/m²), 30 min B. Sulphur pressure (atm)

Fig. 27—Heavily increased CO content in oxidizing gas may eliminate the oxidation-promoting effect of the sulphur

$$\frac{p^2_{CO_2}}{p^2_{CO} \cdot p_{O_2}} = 1·8 \times 10^{13} \quad \text{.....(10)}$$

In equations (6), (7), and (8), p_{O_2} is made equal to 0·01 atm and the partial pressure ratios p_{SO_2}/p_{SO_3}, p_{SO_2}/p_{SO}, and $p^2_{SO_2}/p_{S_2}$ are calculated as 79, $1·5 \times 10^5$, and 10^{17} respectively.

The SO_3, SO, and S_2 contents in the gas may thus be regarded as negligible compared with the SO_2 content. Insertion of CO_2 and O_2 contents in equations (9) and (10) shows that the COS and CO contents will also be negligibly small. Sulphur was added as 0·1% SO_2 and, according to the calculations, should also exist predominantly as such in this gas, i.e. the partial pressure of SO_2 in the gas is practically 0·001 atm. Furthermore, the O_2 pressure is 0·01 atm, and, according to equation (6), the sulphur pressure is thus 10^{-23} atm, which means that the sulphur potential is — 140,000 cal. This sulphur potential lies far below the potential lines for the sulphides of interest and *sulphide formation can thus not take place*; the oxidation proceeds as though the gas were free from sulphur. Calculations have also been made for a gas with 1% O_2 and 1% SO_2. Here again, the sulphur potential is far from sufficient for the formation of sulphide. In Fig. 26 a diagram is reproduced of the SO_2 content in dry flue gas obtained by burning fuel oils of varying sulphur content in 0–100% excess of air.[43] As the diagram shows, 1% SO_2 far exceeds the contents that may occur in oil-firing, and it may be assumed that an insignificant excess of oxygen will prevent the formation of sulphides, even when burning the most sulphur-rich fuels.

When firing with deficiency of air, giving an *excess of CO* in the gas, the result of the sulphur will be quite different. As before, at 1050° C the SO and SO_3 contents may be regarded as negligible compared with the SO_2 content. Moreover, the total fraction of added sulphur (S) is known and it holds that

$$p_{SO_2} + p_{COS} + 2p_{S_2} = S \quad \text{.....(11)}$$

Equations (6), (9), and (10) can be combined into:

$$\frac{p^2_{CO_2} \times p_{COS}}{p^3_{CO} \times p_{SO_2}} = 2·6 \times 10^2 \quad \text{.....(12)}$$

If $p_{CO} = 0·01$ atm, $p_{CO_2} = 0·15$ atm, and $S = 0·001$ are inserted in equations (9), (11), and (12), $p_{SO_2} = 0·98 \times 10^{-3}$ atm, $p_{COS} = 0·11 \times 10^{-4}$ atm, and $p_{S_2} = 0·52 \times 10^{-5}$ atm.

From the value of p_{S_2} the sulphur potential is calculated as — 32,000 cal, which, when inserted in the sulphur potential diagram, is above the equilibrium lines for the sulphides of interest. As small a

Table V

CALCULATED COMPOSITIONS OF COMBUSTION GASES FROM A FUEL OIL CONTAINING 86% C, 12% H_2, 2% S

Gas Type	CO_2, %	CO, %	H_2O, %	H_2, %	SO_2, %	S_2, %	N_2, %	O_2, %
1% O_2 in gas	16·5	...	13·8	..	0·14	$0{\cdot}20 \times 10^{-23}$	68·7	1
1% CO in gas	16·6	1	14·2	0·5	0·13	$0{\cdot}46 \times 10^{-3}$	67·6	...

change in the gas composition as the substitution of 1% O_2 by 1% CO thus alters the sulphur potential of the gas to so high a degree that *the formation of sulphides can take place*.

The sulphides do not form protective layers on the metal surface, and they often melt at the oxidation temperature, but even if they do not, they nevertheless fail to provide effective protection. The rates of diffusion through the sulphides are high and, moreover, the sulphides have a high volume ratio, i.e. high ratio between volume of sulphide and equivalent quantity of metal (usually higher than 2·5), which causes severe stresses in the scale and leads to breaking up of the oxidation front.

Partial pressures of sulphurous constituents have been calculated for varying gas mixtures with CO + CO_2 = 16% and with a total sulphur content corresponding to 0·1% SO_2 (Table IV and Fig. 27). It will be seen that there is a maximum in the S_2 concentration at about 6% CO in the gas, and the oxidation experiments have also given maximum scaling at roughly the same CO content.

The above calculations all apply to gas mixtures without H_2O or H_2. In the presence of these gases there will be still more equilibria to be considered, but the gas compositions can be calculated in these cases as well. Table V shows the result of calculations of the composition of flue gases from burning oil containing 86% C, 12% H_2, and 2% S. The S_2 pressures in the different types of atmosphere will be of the same order of magnitude as with hydrogen-free gases and, as described above, the oxidation structures will also be largely similar.

For the graphical presentation of the gas compositions obtained at different CO, H_2, and O_2 contents, it is advisable to draw a diagram on a logarithmic scale showing the logarithm of the partial pressures of the individual gases as function of the negative value of the logarithm for the partial pressure of the oxygen in the gas.[44] It is always the oxygen pressure—even the very small oxygen pressure encountered in a reducing atmosphere—that determines the gas composition.

Such a logarithmic diagram of the system C–H–O–S

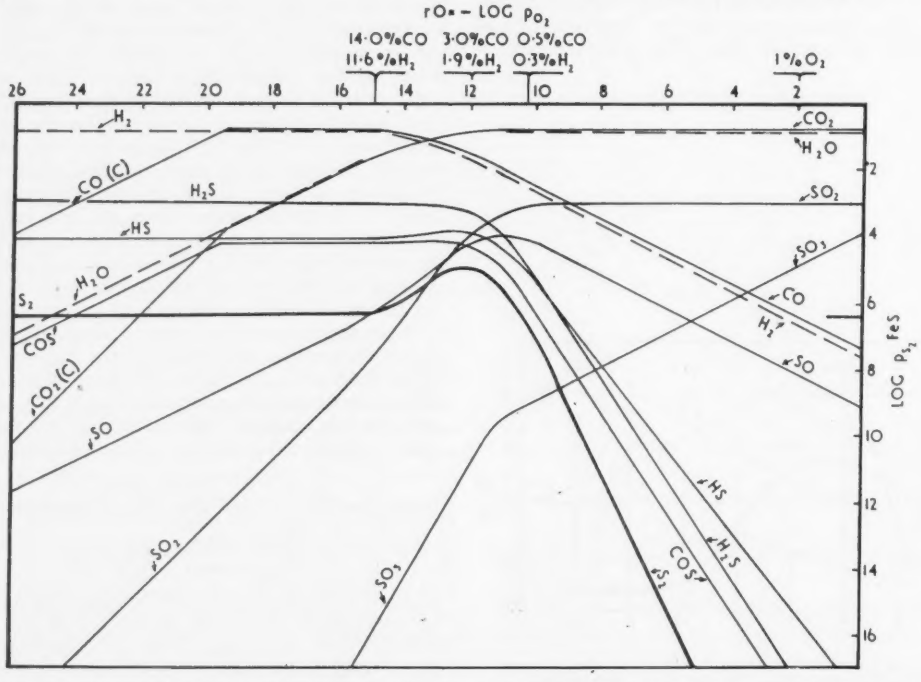


Fig. 28—The system C–H–O–S at 1050° C illustrated in a logarithmic diagram. For every oxygen pressure in the gaseous mixture the partial pressures can be read for the remaining gaseous constituents. The diagram is drawn on the assumption that $p_{CO_2} + p_{CO} = 0{\cdot}16$ atm, $p_{H_2O} + p_{H_2} = 0{\cdot}14$ atm, and total added sulphur corresponds to 0·1% SO_2, p_{CS_2} and p_{CS} are neglected. When the sulphur content in the actual gas corresponds to $a \times 0{\cdot}1\%$ SO_2, by p_{S_2} is obtained from the S_2 curve by adding 2 log a to the value read

Table VI

GAS EQUILIBRIA FOR THE SYSTEM C–H–O–S AT 1050° C

The expression — log p_{O_2} replaced by rO

Reaction	Equilibrium Constant		Equilibrium Equations in Logarithmic Form
	K_p	log K_p	
$2CO + O_2 = 2\,CO_2$	$1{\cdot}8 \times 10^{13}$	13·3	$\log p_{CO_2} = 1/2 \log K_p + \log p_{CO} - 1/2\,rO$
$2C(S) + O_2 = 2\,CO$	$1{\cdot}0 \times 10^{18}$	18·0	$\log p_{CO} = 1/2 \log K_p - 1/2\,rO$
$C(S) + O_2 = CO_2$	$4{\cdot}0 \times 10^{15}$	15·6	$\log p_{CO_2} = \log K_p - rO$
$2H_2 + O_2 = 2H_2O$	$4{\cdot}0 \times 10^{13}$	13·6	$\log p_{CO_2} = 1/2 \log K_p + \log p_{H_2} - 1/2\,rO$
$S_2 + O_2 = 2SO$	$4{\cdot}5 \times 10^{8}$	8·7	$\log p_{SO} = 1/2 \log K_p + 1/2 \log p_{S_2} - 1/2\,rO$
$S_2 + 2O_2 = 2SO_2$	$1{\cdot}0 \times 10^{21}$	21·0	$\log p_{SO_2} = 1/2 \log K_p + 1/2 \log p_{S_2} - rO$
$S_2 + 3O_2 = 2SO_3$	$1{\cdot}6 \times 10^{19}$	19·2	$\log p_{SO_3} = 1/2 \log K_p + 1/2 \log p_{S_2} - 3/2\,rO$
$2CO + S_2 = 2COS$	$2{\cdot}4 \times 10^{-1}$	− 0·62	$\log p_{COS} = 1/2 \log K_p + 1/2 \log p_{S_2} + \log p_{CO}$
$2H_2 + S_2 = 2H_2S$	$9{\cdot}1 \times 10^{1}$	1·96	$\log p_{H_2S} = 1/2 \log K_p + 1/2 \log p_{S_2} + \log p_{H_2}$
$H_2 + S_2 = 2HS$	$1{\cdot}0 \times 10^{-1}$	− 1·0	$\log p_{HS} = 1/2 \log K_p + 1/2 \log p_{S_2} + 1/2 \log p_{H_2}$

at 1050° C is given in Fig. 28. For a given oxygen pressure in the gas the logarithm of the partial pressure of each of the remaining components can be directly read from the diagram, provided that the mixture is in equilibrium. The independent variable —log p_{O_2} is represented[44] by the symbol rO. The greater the value of rO, the more reducing is the mixture. The following assumptions have been made:

(1) The gaseous phase consists of N_2, CO_2, CO, H_2, H_2O, O_2, S_2, COS, HS, H_2S, SO, SO_2, and SO_3.

(2) The sum of the partial pressures of CO_2 and CO is 0·16 atm.

(3) The sum of the partial pressures of H_2O and H_2 is 0·14 atm.

(4) Sulphur has been added in a quantity corresponding to 0·1% SO_2.

These assumptions, in conjunction with the equilibrium equations given in logarithmic form in Table VI, render the system fully conclusive. Taking the logarithm of the variables produces mainly straight lines, which, of course, simplifies the construction of the diagram. It should perhaps be remarked that the discontinuity in the lines for CO, CO_2, and COS at rO 19·5 is due to the fact that, at values of rO larger than this figure, it is the equilibria with solid carbon instead of the pure gas equilibria that will determine the percentages of CO and CO_2 in the gas.

Of primary interest from the sulphide formation aspect is the S_2 curve. As in the system C–O–S (Fig. 27), it has a maximum at rO = 12–13 (2–4·5% H_2 and 3–7% CO), corresponding to the most favourable region for sulphide formation. At rO less than 10·3 (H_2 less than 0·3% and CO less than 0·5%), on the other hand, iron sulphide for instance is no longer formed since the sulphur pressure in the gas is lower than the dissociation pressure of the sulphide. Even at rO greater than 15 (H_2 greater than 11·6% and CO greater than 14%), the sulphur contents are too low to permit the formation of this sulphide.

An example will finally be shown of the appearance of a surface defect caused by the formation of sulphides. Figure 29 represents the specimen shown in unpickled state in Fig. 11, after 10 min pickling in a 40° C acid containing 10 parts by volume conc. HNO_3 and 3 parts 40% HF. The sulphide and oxide phases have been dissolved. The reducing atmosphere has also carburized the steel. Attacks by carbon and sulphur occur simultaneously and, as the sulphides are removed by pickling, one may fail when inspecting a pickled specimen to notice the damaging effect ascribed to sulphur.[15] A direct study of unpickled scale and the neighbouring layer of steel as made in Fig. 11, on the other hand, will provide information on that point.

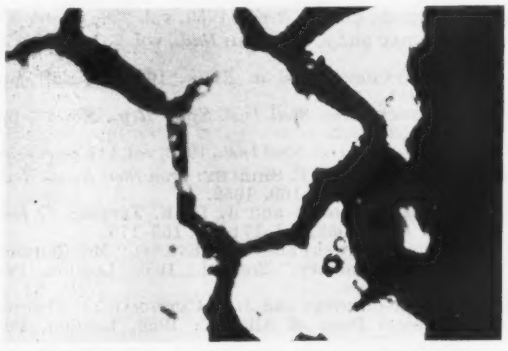


Fig. 29—14% CO_2 + 1·3% CO + 0·1% SO_2 + 85% N_2, 30 min: example of surface damage caused by sulphide formation. Same specimen as in Fig. 11, but the oxide and sulphide phases have been pickled off. The microspecimen is unetched, which explains why carburization is not shown × 600

SUMMARY

(1) The structural pattern of oxide layers formed on 18–8 steel at 1050° C and in different types of atmosphere have been studied by microscopic and X-ray diffraction methods. Special attention was paid to the microstructure of flaking and adherent oxide layers and influence of sulphur on oxidation structures.

(2) The schedule below shows the results of oxidation after treatment in different types of atmosphere.

Sulphur-free gas	
'Reducing' atmosphere (CO excess)	*'Oxidizing' atmosphere* (O_2 excess)
Thin adherent oxide	Thin adherent oxide after short oxidation
Tendency to carburization	Flaky, thick oxide film after long oxidation

	Sulphur-containing gas	
Moderately 'reducing' atmosphere	*Heavily 'reducing' atmosphere (CO > 10%)*	*'Oxidizing' atmosphere*
Adherent thick oxide film	Thin adherent oxide	As for sulphur-free gas
Sulphide formation	Traces of sulphides	
Tendency to carburization	Carburization	

(3) Flaky oxide films formed in different ways consist principally of iron oxides. In an 'oxidizing' atmosphere a transition takes place from adherent to flaky oxide, which is associated with a chemical breakdown of an early formed, slowly growing oxide film with high chromium content. The phase sequence differs in 'oxidizing' and 'reducing' atmospheres, e.g. the formation in a 'reducing' atmosphere of a wüstite layer outside the spinel phase in the scale.

(4) A hypothesis for the mechanism of oxide formation on 18–8 steel has been proposed, which provides an explanation of structural differences in scales formed under dissimilar conditions of oxidation.

(5) In 'oxidizing' atmospheres the presence of sulphur has no effect on the oxidation result, whereas in a 'reducing' atmosphere the presence of sulphur causes sulphide formation and a substantial rise in the rate of scaling. In 'heavily reducing' atmospheres, however, the oxidation-promoting effect of the sulphur disappears.

(6) The differing influence of sulphur on the oxidation process in 'oxidizing' and 'reducing' atmospheres has been explained by calculations of the sulphur vapour pressure in different gaseous mixtures. In a mixture produced by combustion of an oil under conditions of air deficiency, the sulphur pressures are high enough to permit the formation of low melting-point sulphides of Ni, Fe etc. Under conditions of about stoichiometric combustion of the oil, or combustion in excess of air, on the other hand, the sulphur vapour pressures are too low for sulphides to form.

(7) The system C–H–O–S at 1050° C has been illustrated in a logarithmic diagram, from which the partial pressures of the gaseous constituents can be read for every oxygen pressure.

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Effect of Some Common Alloying Elements on the Breakdown of Martensite in a W.Q. 0·35% Carbon Steel

By A. S. Kenneford, M.Sc., F.I.M., Assoc.I.Mech.E., and T. Williams, F.I.M.

SYNOPSIS

The effect of some alloying elements on the breakdown of martensite in a steel containing about 0·35% carbon has been investigated dilatometrically. Of the elements studied, nickel, manganese, chromium, molybdenum, vanadium, and cobalt have little effect on the temperature range over which martensite decomposes into ferrite and cementite. However, chromium, molybdenum, and vanadium delay softening during tempering, and according to the literature this delay is either by inhibiting the spheroidization of cementite (chromium), or by secondary hardening due to complex carbides (molybdenum and vanadium).

Silicon also delays softening during tempering by raising considerably the temperature at which martensite commences to decompose into ferrite and cementite. This effect is of some practical significance in the production of high-strength steels resistant to tempering.

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DURING THE COURSE of an investigation into the mechanical properties of hardened and lightly tempered steel it was thought desirable to determine the effects of several of the commonly used alloying elements on the breakdown of martensite during tempering.

The breakdown of martensite in quenched steel during tempering has been studied by a number of workers who have used mainly X-ray techniques and high carbon steels. This work has shown that, in quenched high-carbon steel, three structural changes occur during tempering:

(i) 1st stage between about 80° and 160° C
(ii) 2nd stage between about 230° and 280° C
(iii) 3rd stage between about 260° and 350° C.

Of these three stages, the second is the decomposition of retained austenite, whilst the first and third are the breakdown of martensite proper, and are caused by the precipitation from the martensite of a close-packed hexagonal carbide of approximate composition $Fe_{2\cdot4}C$,* followed by the eventual decomposition of this carbide and the remaining martensite to ferrite and cementite at higher temperatures.

In the present investigation a Leitz universal dilatometer equipped with a fully automatic temperature programme control was used to record the changes in length of a W.Q. steel specimen during heating to, and cooling from, about 550° C. The rate of heating and cooling used was 2·5° C/min, with an instrument magnification of × 660. The measurement of quite small changes in length was therefore possible, and it was found that the temperature ranges of the first and third stages of tempering (the second stage was generally absent as retained austenite did not occur in most of the steels used) together with the contraction occurring, could be easily measured.

Materials Used

The steels used were in the form of $\frac{5}{8}$-in. dia. bar forged from small h.f. furnace melts and comprised eight series:

Element	*Approximate %*
(i) Carbon	0·3–1
(ii) Silicon	0·5–3
(iii) Manganese	0·5–2·5
(iv) Nickel	0·5–5
(v) Chromium	0·5–3
(vi) Molybdenum	0·25–1
(vii) Vanadium	0·05–0·3
(viii) Cobalt	0·5–4

Note: In series (ii) to (viii) carbon content was about 0·35%.

Complete analyses are given in Table XI.

*K. H. Jack: *J. Iron Steel Inst.*, 1951, vol. 169, pp. 26–36.

Heat-treatment

In general, the heat-treatment of the dilatometer specimens (50 mm long × 3-mm dia.) consisted of soaking in a protective atmosphere at a temperature 50° C above Ac_3 (previously determined dilatometrically) followed by water quenching. There were, however, three exceptions to this general treatment:

(i) Quenching temperature of the hypereutectoid steels was 50° C above Ac_m

(ii) An additional set of carbon-steel samples was refrigerated in liquid air, after water quenching, to eliminate retained austenite as far as possible

(iii) Considering the difficulty with which vanadium carbide is taken into solution in austenite, an additional set of vanadium-bearing samples was quenched from 200 °C above Ac_3 and cooled in liquid air to remove any austenite which may have been present.

RESULTS

(1) Carbon Steels

The effect of increasing carbon content on the temperature of the two stages (I and III) of martensite breakdown is shown in Table I.

A typical dilatometer record for the refrigerated 0·99% carbon steel is shown in Fig. 1.

As might be expected, refrigeration had a marked effect on the volume contraction of the higher carbon steels after tempering (Table II).

Hardness (V.P.N.) determinations on samples of the steels at various stages during tempering showed indications of the beginning and ending of stages I and III of breakdown, stage III being marked more clearly in the lower carbon steels, whilst stage I was more easily shown in the higher carbon materials. In general, however, the various stages of martensite

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Table I

EFFECT OF CARBON CONTENT ON TEMPERATURE OF MARTENSITE BREAKDOWN

Carbon, %	Temperature, °C (W.Q.)		Temperature, °C*	
	Stage I	Stage III	Stage I	Stage III
0·32	103–132	233–403	103–134	232–402
0·49	87–177	245–411	73–177	244–420
0·51	86–178	250–412	76–181	246–425
0·61	82–177	256–424	76–185	246–446
0·70	81–177	260–431	76–191	249–442
0·81	75–193	250–443	76–196	246–444
0·90	76–198	252–447	76–202	247–445
0·99	79–202	247–445	75–204	248–443

* W.Q. and refrigerated in liquid air

Table II

EFFECT OF REFRIGERATION ON VOLUME CHANGE OF W.Q. CARBON STEEL AFTER TEMPERING

Carbon, %	Volume change, %		Difference due to refrigeration
	Quenched	Refrigerated	
0·32	0·324	0·324	0
0·49	0·641	0·641	0
0·51	0·636	0·680	0·044
0·61	0·805	0·864	0·059
0·70	0·916	1·027	0·111
0·81	1·017	1·135	0·118
0·90	1·050	1·227	0·177
0·99	1·076	1·273	0·197

breakdown were not very clearly revealed by alterations in hardness in any of the steels used during these experiments. However, the completion of the stage I of martensite breakdown during tempering has been found to have a marked effect on the mechanical properties of quenched alloy steels, and such steels appear to possess the optimum combination of mechanical properties and hardness when tempered at a temperature corresponding to this particular condition.

(2) Silicon Steels

The effect of varying percentages of silicon on the temperatures of the breakdown of martensite containing about 0·35% carbon is shown in Table III.

These values indicate that silicon had no effect on the temperature of the beginning of stage I of martensite breakdown, but that the end temperature was raised by amounts of silicon in excess of 0·5%. The final stage of tempering, which involves the formation

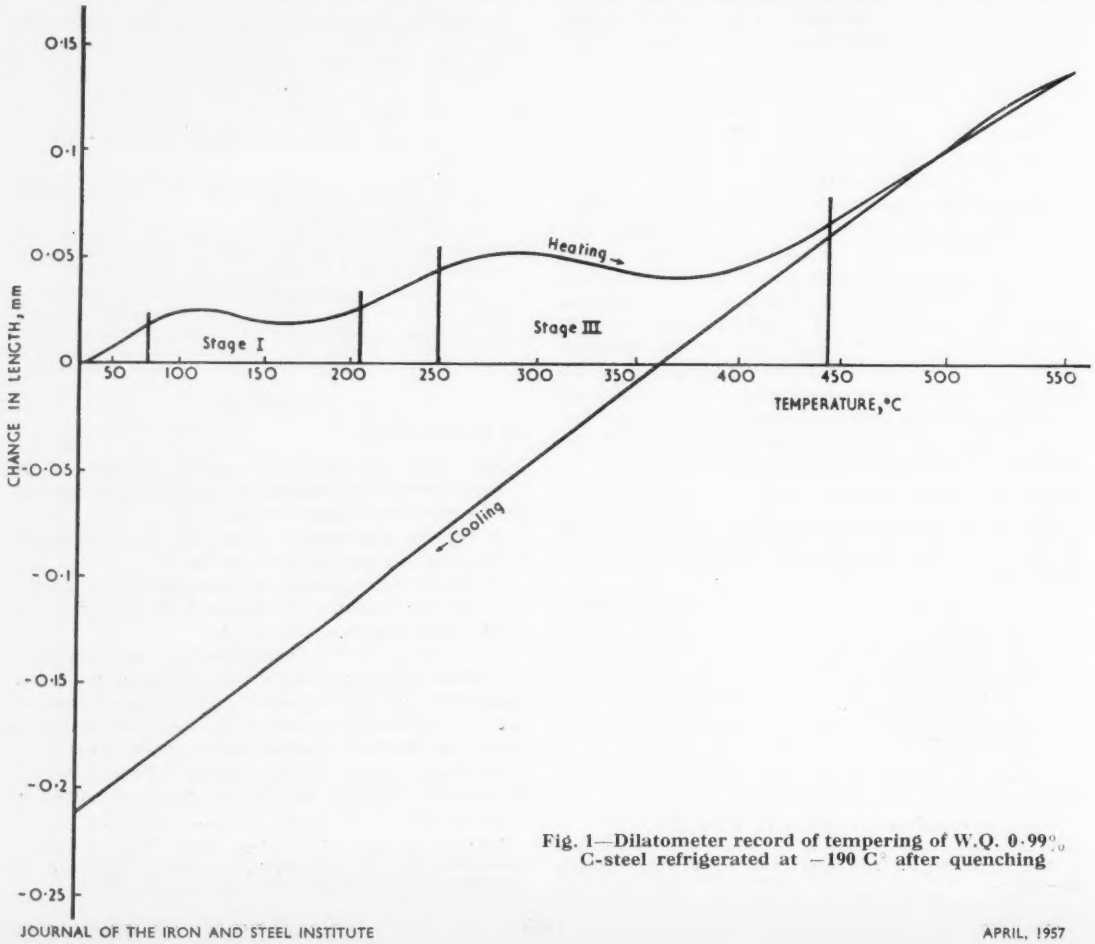

Fig. 1—Dilatometer record of tempering of W.Q. 0·99% C-steel refrigerated at −190 C° after quenching

Table III

EFFECT OF SILICON CONTENT ON TEMPERATURE OF MARTENSITE BREAKDOWN IN W.Q. STEEL CONTAINING ABOUT 0·35% CARBON

Silicon, %	Temperature, °C		Volume Contraction after Tempering, %
	Stage I	Stage III	
0·20	103–132	233–403	0·324
0·48	103–163	270–432	0·355
1·00	104–178	330–459	0·364
1·51	106–177	350–471	0·355
1·98	104–177	356–480	0·356
2·76	106–176	349–488	0·456

of cementite, was considerably and progressively delayed by increases in silicon content, and in the steel containing 2·76% silicon was not completed until the tempering temperature had reached 488° C. A typical dilatometer diagram for the steel containing 2% silicon is given in Fig. 2, and shows clearly the effect of silicon in delaying tempering under the conditions used.

In the case of the higher silicon steels, the two stages of martensite breakdown were clearly visible on the graph of hardness/tempering temperature (Fig. 3). These higher silicon steels were also interesting in that the hardness showed little change over a range of tempering temperatures from about 200° to 350° C. The final hardness after tempering at 550° C also remained at a higher value than would have been anticipated from the carbon content of the steel.

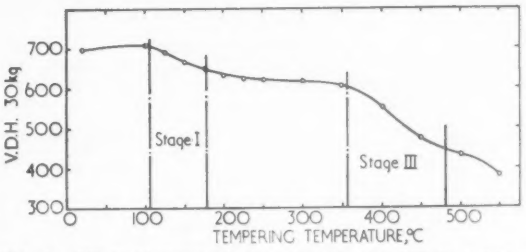

Fig. 3—Effect of tempering on hardness of W.Q. 1·98% Si steel

(3) Manganese Steels

As shown in Table IV, the effect of increasing the manganese content of the steel was to lower slightly the temperature at which the first stage began, and to raise the temperature at which it ended. The start of stage III was unaffected but the end temperature was slightly raised. A typical dilatometer diagram for the steel containing 2% manganese is shown in Fig. 4.

The volume contraction of the steel after tempering at 550° C was increased progressively with increasing manganese content. Apart from the onset of

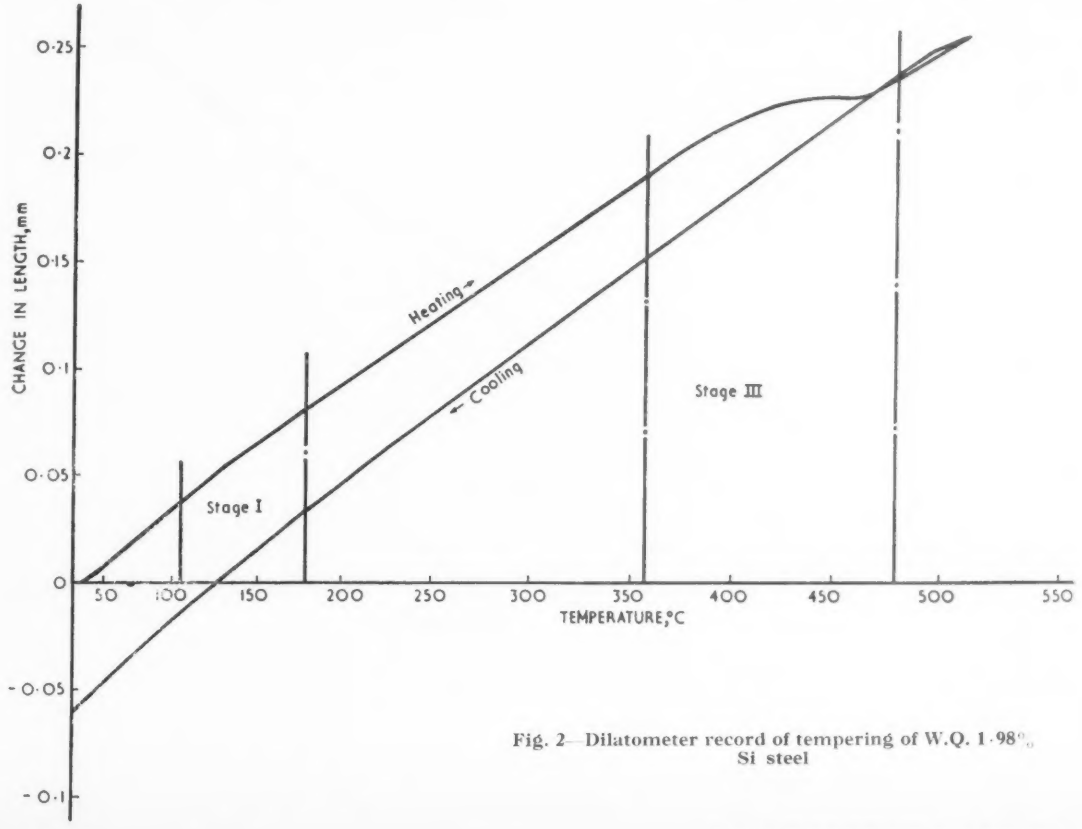

Fig. 2—Dilatometer record of tempering of W.Q. 1·98% Si steel

Table IV

EFFECT OF MANGANESE CONTENT ON TEMPERATURE OF MARTENSITE BREAKDOWN IN W.Q. STEEL CONTAINING ABOUT 0·35% CARBON

Manganese, %	Temperature, °C		Volume Contraction after Tempering, %
	Stage I	Stage III	
0·42	103–132	233–403	0·324
0·95	98–165	230–422	0·350
1·55	90–176	230–423	0·415
2·09	91–176	231–427	0·454
2·54	89–175	232–425	0·464

stage I, the breakdown of the martensite was not shown clearly by hardness measurements after tempering at various temperatures (Fig. 5).

(4) Nickel Steels

Apart from a slight initial raising of the end of the first stage breakdown temperature by the first 0·5%, nickel had a negligible effect on the tempering of martensite. The results obtained are shown in Table V. A progressive increase in volume contraction after tempering occurred as the nickel content was raised.

The results of hardness variation with tempering temperature are shown in Fig. 6 for a 3% nickel steel.

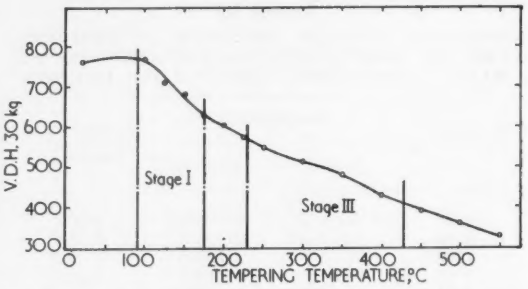

Fig. 5—Effect of tempering on hardness of W.Q. 2·09% Mn steel

(5) Chromium Steels

Table VI shows that the main effect of chromium additions up to 3% was to lower slightly the temperature of the beginning of the first stage of tempering, and at the same time to raise the end temperature of the final stage by about 40° C. From the values obtained for volume contraction after tempering, it will be seen that a maximum occurred with a chromium content of 1·5%.

As in previous instances, the graph (Fig. 7) obtained by plotting hardness/tempering temperature showed only slight changes of slope at the beginning and end of the two stages of tempering.

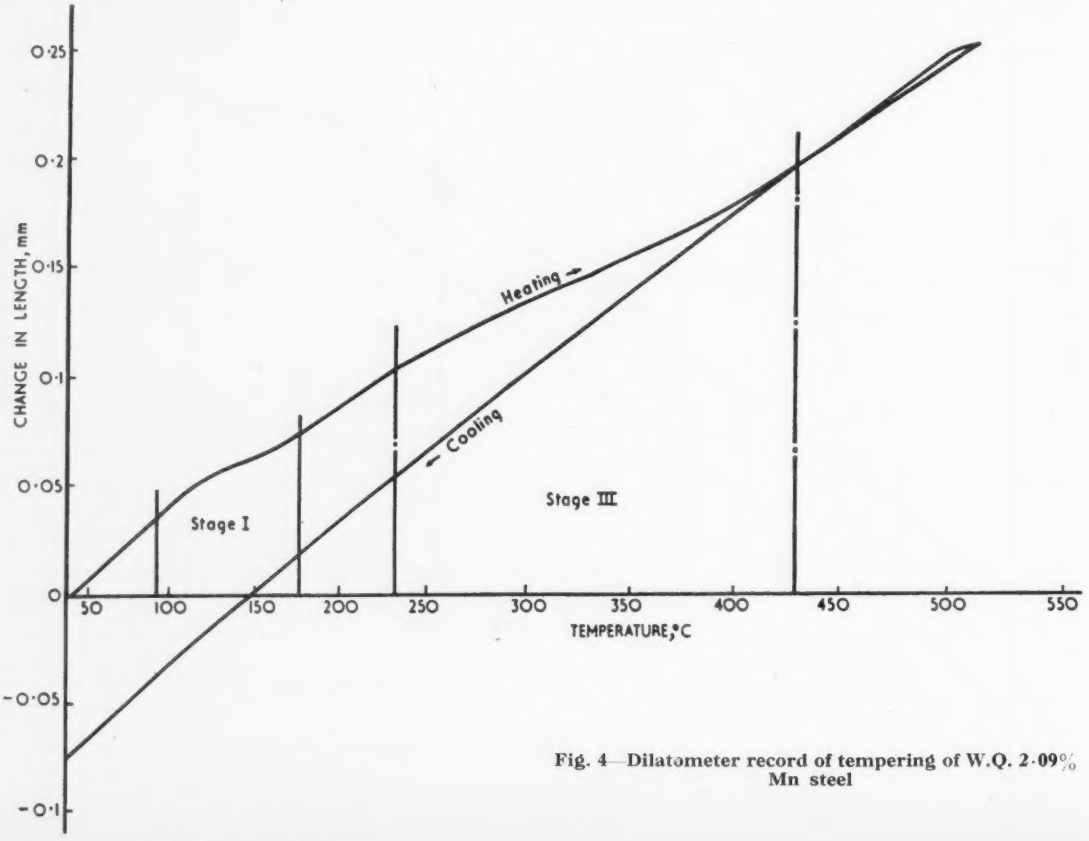

Fig. 4—Dilatometer record of tempering of W.Q. 2·09% Mn steel

(6) Molybdenum Steels

The effect of molybdenum additions up to 1·0% on the temperature of martensite breakdown is shown in Table VII. These values indicate that the resistance of molybdenum steels to softening on tempering is not a result of a raising of the temperature of martensite breakdown, e.g. silicon steels.

Table VII records the effect of increasing molybdenum content on the volume change after tempering at 550° C and shows that the addition of 0·26% molybdenum to a plain carbon steel caused a considerable increase in contraction after tempering. Further additions of molybdenum caused a progressive reduction in this contraction, and with 1·0% molybdenum the volume change was practically the same as that given by the molybdenum-free steel. The effect is similar to that shown by the chromium steels, and by the vanadium steels after normal soaking and quenching, and is probably a result of the formation of carbides other than cementite which do not dissolve easily in austenite.

Hardness measurements on this series of steels after tempering at various temperatures gave little indication of the changes taking place (Fig. 8).

(7) Vanadium Steels

As previously mentioned, vanadium additions to carbon steel result in the formation of carbides soluble only with difficulty in austenite. Consequently, two series of vanadium steel samples were heat-treated as follows: (*a*) soaked 30 min at 810–830° C followed by water quenching, (*b*) soaked 30 min at 960–980° C followed by water quenching and cooling to −190° C to remove any austenite which may have been untransformed during quenching.

The effects of vanadium additions up to about 0·3% on the temperature of martensite breakdown are shown in Table VIII, which indicates that vanadium has no influence. High-temperature soaking, which presumably resulted in the solution of vanadium carbides, raised the temperature of the end of tempering by some 20° C, but did not appreciably alter the other temperatures.

Table VIII shows that for normal soaking and quenching, the volume changes of vanadium steels after tempering followed a course similar to that given by the other carbide forming elements

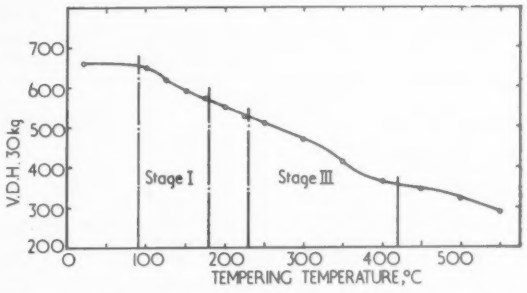

Fig 6—Effect of tempering on hardness of W.Q. 3·07% Ni steel

(chromium and molybdenum) used in these experiments. If, however, the vanadium carbides were taken into solution by a high-temperature soak before quenching, the volume contraction showed a progressive increase with increasing vanadium content.

Hardness determinations in the steels after tempering at various temperatures gave little indication of the two stages of tempering. The 'as-quenched' hardness of the steels containing more than 0·12% vanadium (Fig. 9) was, however, considerably increased by the high temperature soak, though in the steel containing 0·32% vanadium, the maximum hardness based on its carbon content was not reached after soaking for 30 min at 985° C.

The effect of the high temperature soak on the hardness obtained is shown in Table IX.

(8) Cobalt Steels

As will be seen from Table X, additions of cobalt

Table V

EFFECT OF NICKEL CONTENT ON TEMPERATURE OF MARSTENITE BREAKDOWN IN W.Q. STEEL CONTAINING ABOUT 0·35% CARBON

Nickel, %	Temperature, °C		Volume Contraction after Tempering, %
	Stage I	Stage III	
0·56	95–181	237–412	0·336
1·12	87–177	233–418	0·357
2·08	86–177	236–421	0·378
3·07	88–179	230–420	0·404
4·08	88–177	228–418	0·393
5·10	89–176	227–421	0·420

Table VI

EFFECT OF CHROMIUM CONTENT ON TEMPERATURE OF MARTENSITE BREAKDOWN IN W.Q. STEEL CONTAINING ABOUT 0·35% CARBON

Chromium, %	Temperature, °C		Volume Contraction after Tempering %
	Stage I	Stage III	
0·48	99–185	233–412	0·402
1·04	97–182	228–420	0·408
1·51	94–185	236–432	0·436
2·02	93–187	231–440	0·423
2·90	92–183	229–453	0·380

Table VII

EFFECT OF MOLYBDENUM CONTENT ON TEMPERATURE OF MARTENSITE BREAKDOWN IN W.Q. STEEL CONTAINING ABOUT 0·35% CARBON

Molybdenum, %	Temperature, °C		Volume Contraction after Tempering, %
	Stage I	Stage III	
0·26	99–165	229–433	0·405
0·49	98–161	229–431	0·373
0·75	99–162	230–433	0·345
1·00	96–162	230–434	0·330

Table VIII

EFFECT OF VANADIUM CONTENT ON TEMPERATURE OF MARTENSITE BREAKDOWN IN W.Q. STEEL CONTAINING ABOUT 0·35% CARBON

Vanadium, %	Temperature, ° C*		Volume Contraction after Tempering, %	Temperature, ° C†		Volume Contraction after Tempering, %
	Stage I	Stage III		Stage I	Stage III	
0·06	98–163	233–431	0·421	92–159	226–455	0·420
0·12	96–159	227–430	0·450	91–159	228–454	0·482
0·20	94–158	232–432	0·375	89–162	226–453	0·552
0·32	95–159	231–431	0·336	89–161	228–454	0·618

* W.Q. 810–830° C, 30 min soak † W.Q. 960–980° C, 30 min soak, cooled to −190° C after quenching

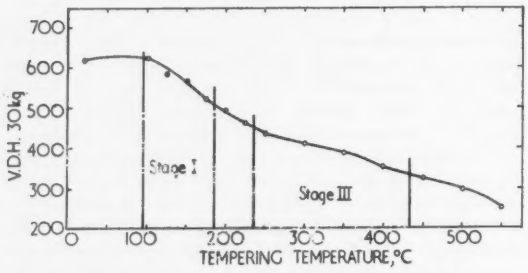

Fig. 7—Effect of tempering on hardness of W.Q. 1·51% Cr steel

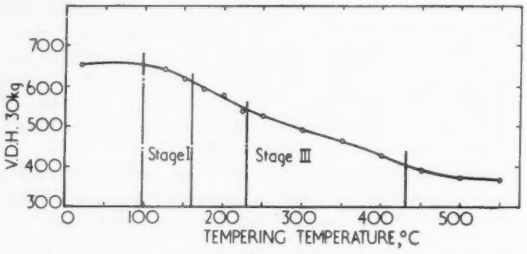

Fig. 8—Effect of tempering on hardness of W.Q. 0·49% Mo steel

up to about 4% were without effect on the temperature of martensite breakdown during tempering.

The results of hardness determinations after tempering the W.Q. 1·92% cobalt steel are shown in Fig. 10. From this graph, the end of the first stage and the beginning of the third stage of tempering can be clearly seen. It will also be noticed that, as in the case of the silicon steels, there was practically no change in hardness value between the end of the stage I and the beginning of stage III, i.e. tempering at temperatures between 175° and 240° C gave an almost constant hardness. Cobalt did not, however, cause any appreciable rise in the temperature of the end of the third stage of martensite breakdown.

DISCUSSION OF RESULTS

Although a considerable amount of work, using mainly X-rays, has previously been carried out on the breakdown of martensite during the tempering of high-carbon steels, the effect of alloying elements on this breakdown in quenched medium-carbon steels appears to have been almost completely ignored. The carbon content of the steels used in the present investigation was around 0·35% which was too low to permit the satisfactory use of X-rays, and consequently a dilatometric method was used.

From the results of the present investigation, it appears that, of all the common alloying elements used, silicon is the only one which delays tempering

Table IX

EFFECT OF SOAKING TEMPERATURE ON HARDNESS OF VANADIUM STEELS AFTER QUENCHING AND TEMPERING

Tempering temp., ° C	V.D.H. (30 kg)							
	0·06% V		0·12% V		0·20% V		0·32% V	
As-quenched	695*	697†	695*	698†	663*	698†	598*	652†
100	682	703	680	685	648	698	599	647
125	664	685	697	671	631	670	557	618
150	632	651	654	651	609	641	578	611
175	618	631	623	631	614	619	571	597
200	580	602	595	591	582	595	554	590
225	564	569	578	562	569	568	532	567
250	529	538	543	541	531	536	495	538
300	501	493	513	504	501	493	476	493
350	441	444	451	443	446	445	431	451
400	394	390	403	396	399	401	388	405
450	350	352	358	358	357	359	360	365
500	330	338	340	343	341	350	339	350

* W.Q. 810–830° C † W.Q. 960–980° C

Table X

EFFECT OF COBALT CONTENT ON TEMPERATURE OF MARTENSITE BREAKDOWN IN W.Q. STEEL CONTAINING ABOUT 0·35% CARBON

Cobalt, %	Temperature, °C		Volume Contraction after Tempering, %
	Stage I	Stage III	
0·48	85–176	240–432	0·405
0·97	85–174	241–431	0·415
1·92	84–178	242–428	0·434
2·85	87·178	244–434	0·456
3·82	81–173	240–432	0·502

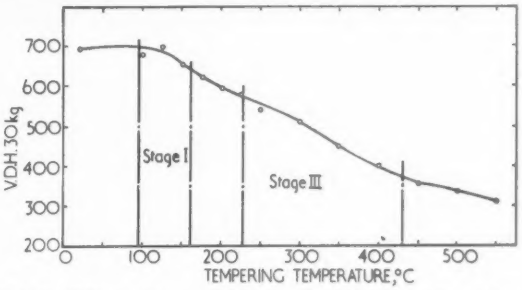

Fig. 9—Effect of tempering on hardness of W.Q. 0·12% Va steel

Table XI

COMPOSITION OF STEELS USED, %

C	Si	Mn	S	P	Ni	Cr	Mo	V	Co
0·32	0·20	0·42	0·030	0·032	...	...	...	...	...
0·49	0·25	0·52	0·006	0·022	...	...	...	...	...
0·51	0·28	0·59	0·006	0·022	...	...	...	...	...
0·61	0·26	0·51	0·007	0·027	...	...	...	...	...
0·70	0·25	0·54	0·007	0·022	...	...	...	...	...
0·81	0·31	0·64	0·006	0·030	...	...	...	...	...
0·90	0·26	0·52	0·007	0·028	...	...	...	...	...
0·99	0·26	0·53	0·007	0·028	...	...	...	...	...
0·31	0·25	0·95	0·011	0·029	...	...	...	...	...
0·35	0·26	1·55	0·012	0·030	...	...	...	...	...
0·38	0·26	2·09	0·013	0·030	...	...	...	...	...
0·38	0·26	2·54	0·012	0·030	...	...	...	...	...
0·35	0·48	0·62	0·005	0·029	...	...	...	...	...
0·34	1·00	0·60	0·013	0·029	...	...	...	...	...
0·35	1·51	0·63	0·012	0·028	...	...	...	...	...
0·37	1·98	0·63	0·012	0·030	...	...	...	...	...
0·39	2·76	0·64	0·011	0·027	...	...	...	...	...
0·34	0·22	0·44	0·032	0·031	0·56	...	...	...	...
0·35	0·22	0·46	0·032	0·036	1·12	...	...	...	...
0·33	0·22	0·46	0·033	0·030	2·08	...	...	...	...
0·35	0·22	0·45	0·030	0·033	3·07	...	...	...	...
0·34	0·24	0·48	0·032	0·033	4·08	...	...	...	...
0·35	0·22	0·45	0·030	0·034	5·10	...	...	...	...
0·35	0·24	0·48	0·033	0·032	...	0·48	...	...	...
0·36	0·25	0·48	0·033	0·031	...	1·04	...	...	...
0·37	0·23	0·46	0·032	0·032	...	1·51	...	...	...
0·36	0·24	0·49	0·033	0·032	...	2·02	...	...	...
0·35	0·23	0·44	0·033	0·032	...	2·90	...	...	...
0·37	0·24	0·61	0·013	0·030	...	...	0·36	...	...
0·35	0·23	0·56	0·013	0·033	...	...	0·49	...	...
0·38	0·25	0·58	0·013	0·031	...	...	0·75	...	...
0·35	0·25	0·58	0·015	0·032	...	...	1·00	...	...
0·38	0·25	0·61	0·006	0·030	...	...	...	0·06	...
0·38	0·29	0·61	0·006	0·032	...	...	...	0·12	...
0·35	0·26	0·59	0·006	0·031	...	...	...	0·20	...
0·37	0·25	0·59	0·006	0·029	...	...	...	0·32	...
0·37	0·24	0·59	0·007	0·029	...	...	...	...	0·48
0·38	0·26	0·61	0·005	0·024	...	...	...	...	0·97
0·35	0·28	0·61	0·006	0·026	...	...	...	...	1·92
0·36	0·25	0·61	0·006	0·023	...	...	...	...	2·83
0·37	0·25	0·59	0·006	0·025	...	...	...	...	3·82

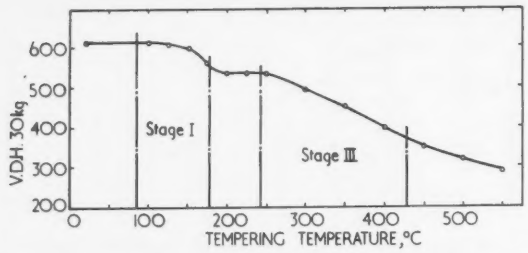

Fig. 10—Effect of tempering on hardness of W.Q. 1·92% Co steel

by raising the temperature at which martensite decomposes into ferrite and cementite. This effect has considerable practical significance in the production of high-strength steels resistant to tempering.

Of the other elements investigated, cobalt behaves similarly to silicon, in that it delays softening of the steel over a temperature range between the end of the first and beginning of the third stage of tempering. It does not, however, raise the temperature at which ferrite and cementite begin to form, and hence does not raise the temperature at which the steel becomes fully tempered. Nickel seems to be entirely without influence on the various changes occurring during tempering, whilst chromium, molybdenum, and vanadium all delay softening during tempering, but do not greatly affect the temperature ranges over which the decomposition of martensite takes place. In the case of these strongly carbide-forming elements, this effect is stated to be caused by secondary hardening due to double carbides.*

Acknowledgments

Thanks are due to Dr. L. Northcott for the interest shown, and to Mr. W. E. Bardgett, Central Research Department, United Steel Companies, Ltd., for supplying the steels used.

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*E. C. Bain: e.g. *see J. Iron Steel Inst.*, 1955, vol. 181, pp. 193–212.

Specific Heat and Resistivity of Mild Steel

By P. R. Pallister, Ph.D.

SYNOPSIS

The 'spot' method has been used for the measurement of the specific heat of mild steel from room temperature up to 1000° C in such a way as to approach equilibrium conditions. The investigation involved thermal analysis at various rates of heating and cooling and also observations on electrical resistivity over the same range of temperature. 1281

Introduction

THE OBJECT of the work here recorded was primarily to measure the specific heat of a low-carbon steel from ordinary temperatures up to 1000° C by a method which would as far as possible avoid retention of unstable constituents. Electrical resistivity entered incidentally into the calculation of specific heat.

It had been found[1, 2] with high-purity iron, in the range of temperature where both alpha and gamma iron coexist, that 'spot' values of specific heat were depressed if the time of heating over that range were protracted. A typical series of measurements comprised successive, sudden, small increments in temperature separated by relatively long intervals of time at approximately constant temperature. The conclusion was drawn that the absorption of latent heat distributed itself over the whole period, during which the temperature was both varying and stationary. It seems reasonable to suppose that, if a phase change of a kind normally taking place with absorption of heat at constant temperature be retarded so that the temperature begins to rise before the transformation is complete, the transformation may proceed continuously along a path which includes isothermal portions. When these isothermal portions occupy a long period compared with the duration of the incremental jumps in temperature, the heat absorption manifested during the increments may become negligible. Therefore, whilst continuous heating methods afford apparent specific heats which include heats of transformation, 'spot' measurements with adequate intervals between them might

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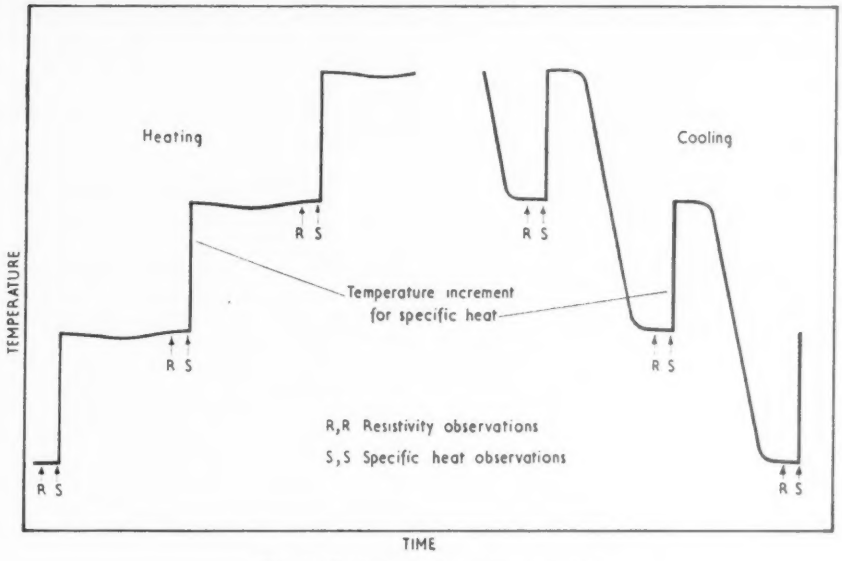

Fig. 1—Sequence of measurements

afford virtually true specific heats throughout the phase change. If this presumption were confirmed, those methods for specific heat which involve the rapid cooling of specimens in a calorimeter would be found defective in the transformation region of temperature because the time of holding at each temperature in that range would influence the amount of heat evolved. The martensitic reaction would become a disturbing factor only at high rates of cooling.

Steels notoriously exhibit thermal hysteresis and much work has been performed upon them. The continuous heating method of Awbery and Snow[3] clearly shows the absorption of heat during transformation in a series of annealed carbon steels. On the same series, electrical resistivity measurements[4] and thermal analysis[5] have been carried out, so that some correlation of metallurgical and physical features is possible. It is evident that in such experimental work the prevailing conditions differ from those to which a simple iron–carbon equilibrium diagram applies. A steel of eutectoid composition gives a specific-heat/temperature curve with one peak at the eutectoid temperature, consistent with the equilibrium diagram. The hypo-eutectoid curves are more complex. A low-carbon steel discloses a peak or peaks at the Ac_1 region where pearlite transforms to austenite accompanied by absorption of heat: the adjacent peak at the Curie point (Ac_2) is merely a maximum of true specific heat: the higher temperature peaks of Ac_3 include heat associated with transformation of residual ferrite to austenite. Between Ac_1 and Ac_3 there will be absorbed the heat of solution of ferrite in austenite. The continuous method for specific heats does not readily lend itself to measurements in the direction of cooling. The 'spot' method, however, may be used intermittently in both directions, and it is particularly desirable to make such measurements in the A_1 and A_3 regions where large heat changes occur. Figure 1 shows the contemplated sequence of measurements. A low-

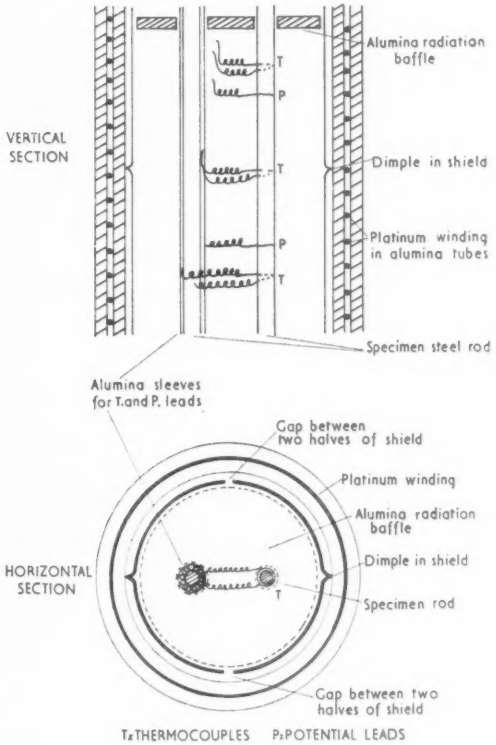

Fig. 2—Furnace assembly

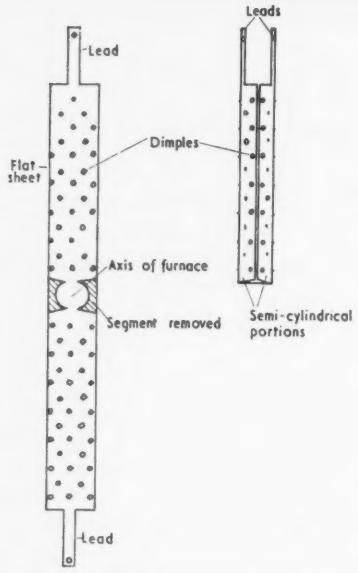

Fig. 3—Shield construction

carbon steel has been chosen for this purpose, and thermal analysis was carried out as an essential preliminary. For all the measurements made the rod of steel was in the annealed condition.

THE SAMPLE OF STEEL

A rod of mild steel, $\frac{1}{4}$ in. dia. and 6 ft long, served for the purpose of this investigation. Its density was found to be 7·84 g/cm³. Analysis by the British Iron and Steel Research Association afforded the following composition: C, 0·13%; Si, 0·20%; Mn, 0·61%; Cr, 0·01%; Ni, 0·12%. It would therefore fall into the category of En 2 of British Standard 970 : 1947.

THE FURNACE ASSEMBLY

The welded furnace body, 3 ft 6 in. high and 10 in. dia., was constructed of $\frac{1}{4}$-in. steel plate and fitted with a $\frac{1}{2}$-in. steel flange at the mouth. The test rod of steel was bent into **U** form and suspended centrally from stout leads which passed out of the furnace body through porcelain plugs. Surrounding the rod was a nickel shield, made from sheet metal and comprising two semi-cylindrical portions joined at the base. Figures 2 and 3 illustrate the arrangement. Gaps were maintained between the vertical edges of the two portions so that they were electrically in series. The shield was embossed with a regular array of dimples to prevent undue thermal contact with the furnace tube. Separate terminals on the furnace were provided for the shield leads. The furnace tube was alumina of 2 in. bore, wound with a helix of platinum wire, the pitch of which gradually increased towards the middle, with the object of securing uniformity of temperature. The winding was set with alumina cement within another alumina tube. Trebled leads connected with terminals on the furnace body. Thermal insulation for the furnace tube was provided by standing it on a 6-in. block of alumina and surrounding it with alumina powder. Alumina discs were supported on the specimen rod at 4-in. intervals in order to maintain the rod symmetrically in the furnace tube and also

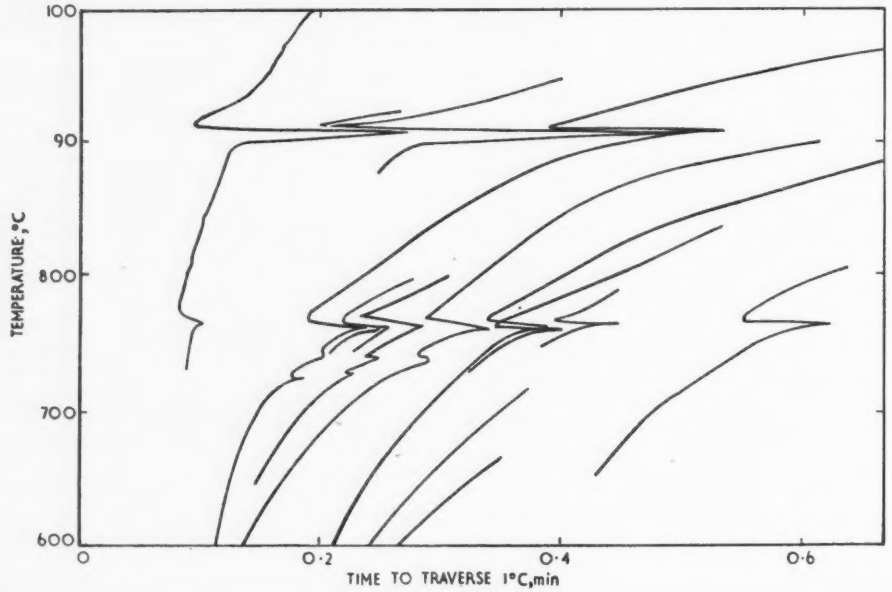

Fig. 4—Heating curves

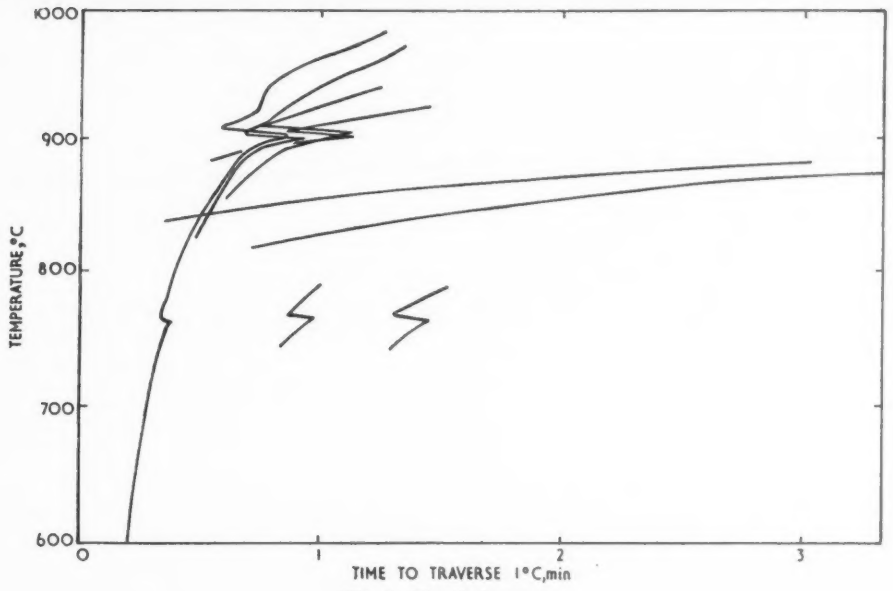

Fig. 5—Heating curves

to improve temperature uniformity by obstructing heat loss by radiation. Thermocouples and platinum potential leads were welded to the rod and led via alumina sleeves to a wax seal in the lid. A plug of alumina at the top of the furnace tube completed the thermal insulation. The lid was sealed by means of an O-ring and evacuation carried out to about 0·01 mm Hg. The furnace current was controlled manually by Variac autotransformer and resistors and stabilized by a constant-voltage transformer. A load of $\frac{1}{2}$ kW sufficed for every demand, and the insulation in these circumstances proved to be so effectual that no external water-cooling was required, either around the body or through the hollow lid of the furnace.

In order to locate the most uniformly heated part of the rod, numerous thermocouples of both platinum/rhodium–platinum and chromel/alumel were attached

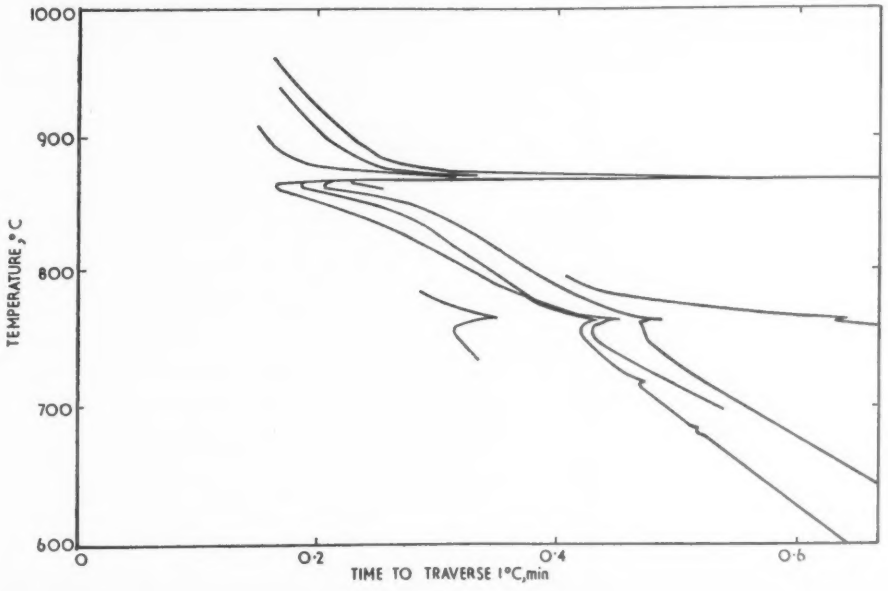

Fig. 6—Cooling curves

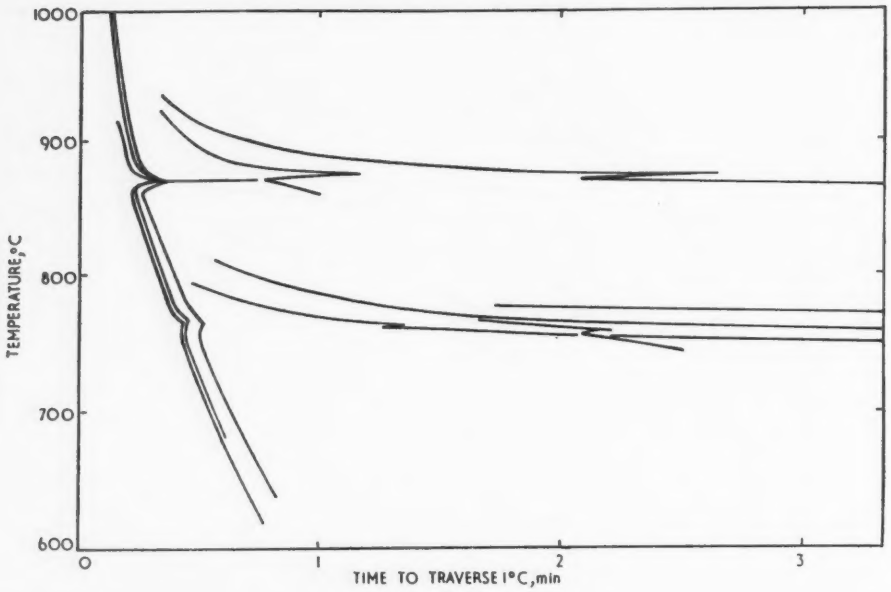

Fig. 7—Cooling curves

to it. The selected part, about 5 cm in length, was free of temperature variations exceeding 2° C at the highest temperatures reached. All measurements were then restricted to that part of the rod in order to observe thermal effects modified as little as possible by thermal gradients. The temperature could be readily adjusted to a predetermined value and maintained there within 0·01° C. When necessary, a temperature of 1000° C could be attained in 1 h, supplementary direct electrical heating of the specimen rod and shield facilitating the process. The thermocouples were frequently renewed to avoid uncertain temperature indication.

Table I
ARRESTS IN HEATING CURVES

Heating Rate, Approaching an Arrest, °C/min	Temperature of the Arrest, °C
5·6	725
5·0	741
4·5	726
4·2	739
3·6	738
10·0	764
4·5	761
4·2	761
4·0	761
3·6	761
3·0	760
2·6	762
2·5	760
2·3	763
1·6	763
1·0	764
0·7	763
8·3	907
3·9	906
3·9	907
2·3	907
1·4	900
1·3	900
1·2	901
1·2	903

THERMAL ANALYSIS

Although the furnace had been specially designed for the measurement of specific heat, it lent itself also to the needs of crude thermal analysis. Heating and cooling curves were taken at rates up to 10° C/min. Temperatures were measured thermoelectrically with a vernier potentiometer and the times taken for changes of approximately 1° C were determined by stop watches. Closer temperature intervals were observed at critical points and all results were converted to apply to one degree for the construction of inverse-rate curves. The heating curves are shown in Figs. 4 and 5 and the cooling curves in Figs. 6 and 7. Some of the curves overlap, but the individual curves have been inspected for arrests, with the results given in Tables I and II. Here an arrest is regarded as occurring where the incline or decline of a curve becomes minimal.

ELECTRICAL RESISTIVITY

A steady current of about 1 A was passed through the steel rod and a comparable standard resistor in series. The potential difference across the uniformly heated segment of the rod, defined by the positions of two potential leads, and the potential difference across the standard were compared by potentiometer. The junctions of the platinum potential leads and the copper potentiometer leads were maintained at 0° C. On reversal of the current the potential difference across the specimen remained substantially

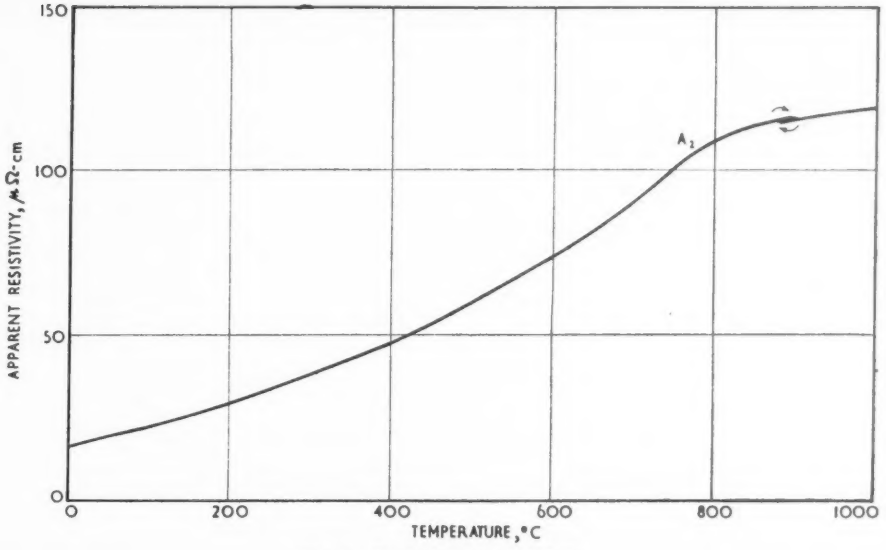

Fig. 8—Resistivity, 0–1009° C

the same numerically, as long as temperatures were not far removed from room temperature. With rise in temperature a discrepancy appeared and attained a significant level, due to thermal electromotive forces in the circuit. A residual e.m.f. equal to half the discrepancy, however, remained on stopping the current and therefore allowance could be made for the adventitious e.m.f. The thermal e.m.f. could be eliminated alternatively by taking the mean of the two indicated potential differences for direct and reversed current.

Such a resistance measurement was made regularly at a steady temperature just before each specific-heat determination. In addition, several extensive series of resistance measurements alone were made and the aggregate was used to draw up the curve of Fig. 8. It is impossible to show clearly the 1200 observation points, the curve given being true to better than 0·2%. The error in reproducibility of the value of resistance in two consecutive measurements at sensibly the same temperature was less than 0·1%. Resistivities were calculated with respect to the dimensions measured initially at room temperature and are therefore described as apparent resistivities. Permanent changes in length up to ± 0·3% brought about by heating and cooling were observed each time the furnace was opened for replacement of thermocouples. The hysteresis loop at approximately 900° C was confirmed by several series of measurements, carried out at an overall mean rate of heating and cooling of 0·2° C/min. The values of resistivity at selected temperatures are included in Table III.

SPECIFIC HEAT

The design of apparatus used in earlier investigations of specific heat was modified, principally in the provision of separate electrical heating circuits for the specimen rod and its cylindrical shield. By this means different currents could be simultaneously passed through the two circuits, adjusted in the desired ratio, according to the temperature at which measurement was to be made. It was required that, if the temperature of the rod and the shield were to rise equally and simultaneously,

$$I_R/I_S = A_R \sqrt{(d_R\, c_R\, \rho_S)}/A_S \sqrt{(d_S\, c_S\, \rho_R)}$$

where I is the current, A the cross-sectional area, d the density, c the specific heat, and ρ the resistivity. The subscripts R and S refer to the rod and shield

Table II

ARRESTS IN COOLING CURVES

Cooling Rate, Approaching an Arrest, °C/min	Temperature of the Arrest, °C
5·9	868
5·0	868
4·5	868
4·3	869
4·0	868
4·0	868
1·0	873
0·5	873
3·3	764
2·5	764
2·4	762
2·3	762
2·2	764
2·1	762
2·0	764
1·6	763
0·8	762
0·5	759
2·2	717
2·0	718
1·9	684

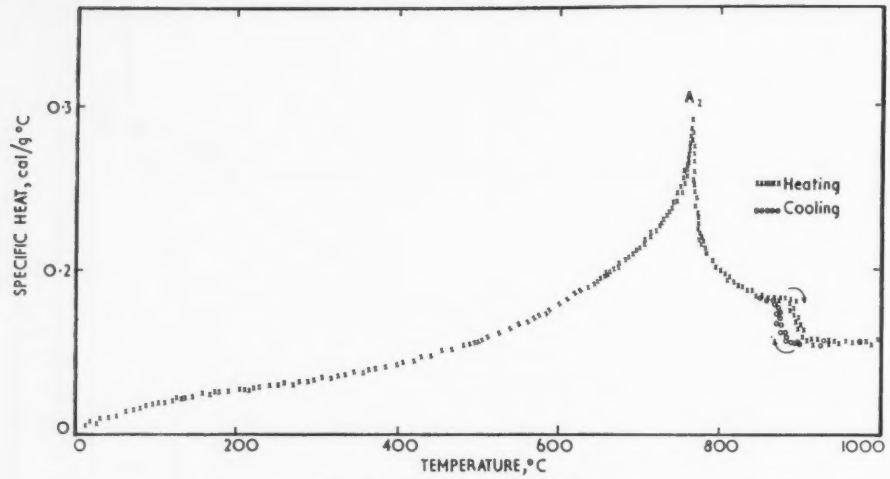

Fig. 9—Specific heat, 0–1000° C

respectively. The heating currents thus pre-arranged were started and stopped simultaneously by a heavy-duty contactor which was operated by relay. The same relay current operated a precision interval timer based upon a synchronous motor. I_R was varied by specially constructed manganin resistors up to 150 A; I_S was always lower. The time interval for heating the rod and shield was about 1 s, which sufficed to permit reading of a freshly calibrated ammeter. The temperature increment, usually about 1° C, was obtained by measurement of the increase of thermal e.m.f. in the thermocouple which was attached to the middle of the specimen.

Table III
RESISTIVITY AND SPECIFIC HEAT

Temperature, °C	Apparent Resistivity, μΩ-cm	Specific Heat, J/g °C
0	(16·3)	(0·435)
20	17·7	0·444
50	19·3	0·464
100	22·6	0·494
150	26·0	0·511
200	29·6	0·527
250	33·7	0·540
300	38·2	0·557
350	43·0	0·578
400	48·2	0·598
450	54·1	0·628
500	60·3	0·662
550	67·1	0·699
600	74·2	0·754
650	82·2	0·817
700	91·0	0·900
740	99·4	1·01
763	104·3	1·22
780	107·3	0·891
800	110·0	0·833
840	113·8	0·783
868	115·3	0·762
906	116·1	0·657
950	117·8	0·653
1000	119·4	0·657

A simple cooling curve, which was nearly straight over the first half minute, enabled a small correction for loss of heat to be made. It was found convenient, having balanced the potentiometer for the initial steady temperature, to advance the potentiometer reading in anticipation of the increment and then observe the out-of-balance deflection of the potentiometer galvanometer. The ideal value of I_R/I_S could be departed from substantially without prejudicing unduly the accuracy of the measurement. Exhaustive tests were made on the reliability of the timing device by repeating observations at a fixed temperature with varying currents and durations of heating. The values of specific heat obtained were considered to be correct to 2%. Hysteresis accounted for the distinct loop in Fig. 9 near 900° C, several series of confirmatory measurements being taken, for which heating and cooling rates were approximately 0·2° C/min. Numerical results at selected temperatures are included in Table III.

DISCUSSION OF RESULTS

The energy changes at the A_1, A_2, and A_3 points are shown on the inverse-rate curves of Figs. 4, 5, 6, and 7 and the actual temperatures of the corresponding arrests are conveniently grouped together and plotted against rate of heating or cooling in Fig. 10.

The arrests in the A_1 region, which are quite distinct on the fast inverse-rate curves, become indiscernible on the slower curves. The double arrest which occurs in some curves may arise by virtue of the presence of elements other than iron and carbon. The disappearance of the one arrest or of both seems to point to a spreading of the transition between pearlite plus ferrite and austenite plus ferrite over

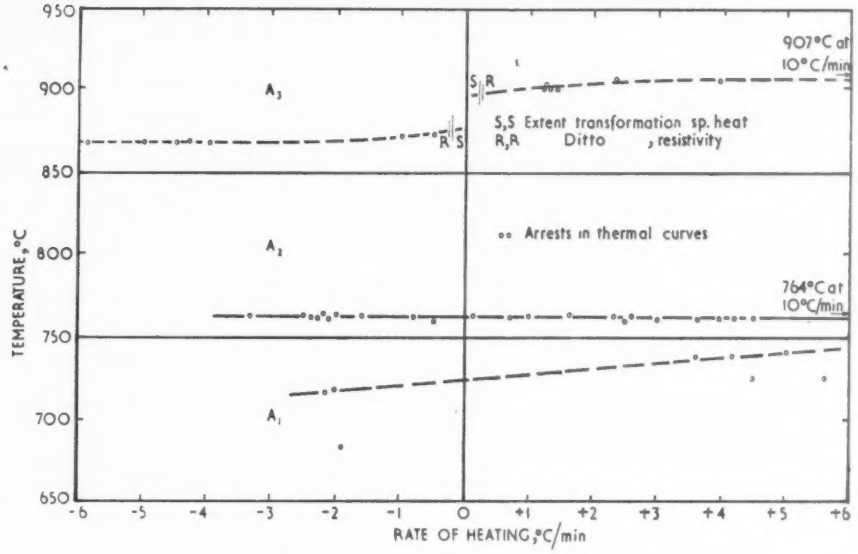

Fig. 10—Temperatures of arrests

an undetermined temperature range. The absence of even a distinct bulge on some of the curves leaves it uncertain just how extensive this range may be. Interpolation between the upper A_1 arrests on Fig. 10 to zero rate of heating suggests 723° C approximately as the probable equilibrium eutectoid temperature. It would be anticipated on the strength of these observations that the specific-heat measurements, which are necessarily made under almost stationary conditions of temperature, would not indicate any noticeable peaks, even if a small amount of latent heat were included.

Both Ac_2 and Ar_2 arrests show a slight irregular diversity around 762° C, and this value may be accepted for Ac_2. It is clear from the inverse-rate curves that the specific heat would increase continuously as this point is approached and then drop rapidly.

The A_3 arrest is well marked on both heating and cooling inverse-rate curves, where evidently considerable energy changes are involved. Whilst the Ac_3 arrest varies from 900–907° C, the Ar_3 arrest is always lower, varying from 868–873° C, and the heat effect during cooling is more abrupt. A distinct halt in temperature was in fact generally observed in the cooling curves. The heating and cooling arrests plotted in Fig. 10 have a tendency to converge as zero rate of change of temperature is approached, but further accessory data from resistivity and specific-heat observations help in this matter. It might be anticipated, however, from the arrests plotted that hysteresis would persist even at very slow rates of heating and cooling, and lead to more than one value of specific heat at any temperature in that range. The absorption and evolution of heat associated with the transformation could affect the measured values of specific heat. The temperatures at which discontinuities in physical properties might occur having been located, it is interesting to survey the actual results of the investigation of resistivity and specific heat.

The well established resistivity curve of Fig. 8 is continuous in the A_1 region and no irregularities occur outside the stated possible experimental error. The curve suffers an inflexion at the A_2 point after having attained its maximum slope.

As the temperature increases the slope gradually decreases and at 892° C decreases more rapidly, becoming zero at 897° C and then negative until 906° C is reached. At this point a positive slope is resumed rather rapidly and again the slope decreases gradually up to the limit of observation, 1000° C. Evidently the Ac_3 range of temperature for the relevant rate of heating is 892–906° C. Observations during cooling reproduce the values of resistivity down to 906° C and continue along the lower part of the loop to 878° C, where an abrupt turn occurs. The cooling curve rejoins the heating curve at 871° C and then follows it in the reverse direction. The Ar_3 range may be taken in these circumstances to be 878–871° C.

The specific-heat curve of Fig. 9 shows an increase continuously up to 763° C, a point of inflexion appearing at about 150° C and maximum slope at 763° C. No indication of a latent heat is given in the A_1 region during this slow heating process. Immediately above 763° C the fall in specific heat is very rapid and it continues to fall more slowly to about 888° C, and then more rapidly to 904° C. At this point it becomes sensibly constant and has a slight tendency to rise above 950° C. The Ac_3 range is taken as 888–904° C. In the direction of

cooling the lower part of the loop is followed and the Ar_3 range taken as 884–868° C. The confirmatory measurements of specific heat round the loop were made at approximately the same overall rates of heating and cooling, as shown in Fig. 10. Under these conditions the 'spot' measurements of specific heat appear to apply to true specific heats devoid of other contributions and the slopes of the sides of the hysteresis loop depend upon the relative proportions of alpha and gamma iron present during each transition. Nevertheless, it is possible that with even more protracted transitions greater slopes might have been obtained, resulting in a more slender loop. The effect would then be to reduce the gap between the centres of Ac_3 and Ar_3. As the measurements stand, the centres of Ac_3 and Ar_3 are taken as 896° and 876° C respectively, and these points are inserted in Fig. 10, together with similar data from the resistivity measurements. The trend of the A_3 arrests in Fig. 10 is to converge at zero rate of heating, yet according to these measurements, the lowest temperature at which there is evidence of the Ac_3 transformation is 888° C and the highest temperature of the Ar_3 transformation is 884° C. There is therefore a small gap between them, but some ground is given by these measurements for concluding that, if it were possible to reach the required condition, the Ac_3 point for this steel would be approximately 886° C.

In reviewing this investigation, it appears that the 'spot' method for specific heats has provided data which apply to mild steel in a nearly stable condition. The curve up to 1000° C is similar in general shape as for high-purity iron except in the detail at the A_3 region.

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The Potentiostat as a Metallographic Tool

By C. Edeleanu, M.A., Ph.D.

Introduction

A TECHNIQUE which has been initially developed for the study of certain corrosion phenomena, and in particular the passivity of stainless steels, seems to have applications in metallographic studies, and the purpose of the paper is to outline some of these.

The technique which has been described elsewhere[1,2] involves maintaining the potential of a specimen immersed in a solution at any desired potential relative to a standard electrode by the use of a potentiostat.[3] If the solution is correctly chosen it is then found that in many cases there is a relatively simple relation between potential and the rate of dissolution of the metal in the solution, and the full line of Fig. 1 shows diagrammatically the type of curve obtained with a high Cr–Ni steel in, for example, sulphuric acid. The exact position of the curve depends on the acid concentration, the temperature, and the alloy used. If the first two of these variables are kept constant, it is possible, if desired, to find how the position of the curve alters with composition, and this is now being done for a number of alloys since it is of interest from a corrosion point of view. It is not, however, essential for purely metallographic studies, and the only important point to appreciate is that a change in composition almost certainly will also involve a shift of the curves as indicated by the dotted line of Fig. 1 which, in this case, is meant to represent diagrammatically the case of an alloy containing a somewhat higher chromium and lower nickel content than the one represented by the full line.

SYNOPSIS

It is suggested that the potentiostat, an instrument which can maintain the potential of a working electrode at any desired value, may find uses in metallographic studies. It is shown with some high chromium–nickel alloys how it is possible to use the instrument for controlled etching, for the detection of susceptibility to intercrystalline corrosion, and in the study of phase diagrams. 1303

ETCHING TECHNIQUE

If the alloy contains two or more phases, each phase will behave more or less independently of the others; if now the potential is so chosen that one of the phases corrodes very much more rapidly than the others, this will lead to differential etching of that phase.

This can be easily demonstrated with a simple duplex alloy, but an 18–8–3–1 Cr–Ni–Mo–Ti steel has been chosen since it presents a more difficult case and one which requires a great deal of skill to study by conventional means.

The composition of the steel used was:

C, %	Si, %	Mn, %	Cr, %	Ni, %	Mo, %	Ti, %
0·05	0·55	0·70	18·42	8·73	2·85	0·24

The first set of experiments was carried out with the steel water-quenched from 1150° C. In this condition the steel is a simple duplex alloy containing delta-ferrite, which is higher in chromium and lower in nickel than the austenitic phase.[4,5]

As might be expected from Fig. 1, there should be a certain high potential at which the delta is selectively

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Dr. Edeleanu, who was with the Brown-Firth Research Laboratories, Sheffield when this work was carried out, is now with the Tube Investment Research Laboratories.

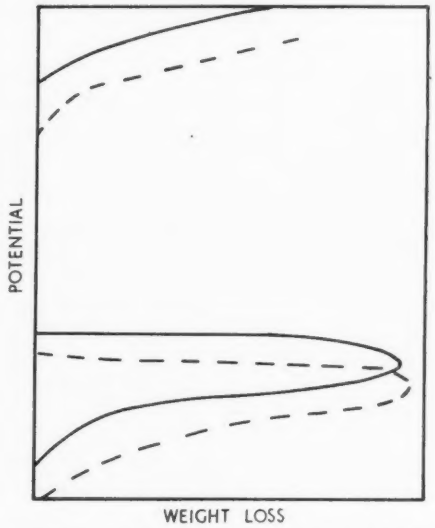


Fig. 1—Diagrammatic weight-loss/potential curves for Cr–Ni stainless steels in sulphuric acid. Full line represents a steel lower in chromium and higher in nickel than the broken line

etched; below this there should be a relatively wide range of potentials where nothing much happens. The austenite should be selectively etched at some intermediate value, while the delta phase should then again etch preferentially at an even lower value. Figures 2*a–c* show that this is the case, and the captions give the actual potential values* for a 20% sulphuric acid solution which has been used in all experiments unless otherwise stated.

If this alloy is now aged at, for instance, 850° C, sigma phase starts precipitating from the delta-ferrite and at the same time a 'new' austenite is being formed. It is almost certain that the new austenite has, at least in the early stages, a somewhat different composition from the existing austenite. The mechanism of the reaction, which has been previously studied,[4–7] is obviously complex and it is outside the scope of this paper to comment on it. The main purpose is to show how, by carrying out etching experiments at various potentials on specimens aged for 4 h at 850° C, quite different portions of the alloy can be selectively attacked.

Figure 3*a* shows how, by working at a high potential, it is possible to distinguish between what is thought to be untransformed delta-ferrite and sigma phase. When the potential was lowered to the value at which the parent austenite was known to etch, it was possible to distinguish between the new and old austenite (Fig. 3*b*).

If now the alloy is treated for 6 days at 850° C, the transformation to sigma is almost complete and diffusion largely evens out the difference in composition between the new and old austenite, but some difference probably still exists, as shown by Fig. 4, which also shows that precipitation of either sigma or carbide is occurring within the grains of austenite and, in places, at what are assumed to be the old delta phase boundaries.

* All potentials are on the saturated calomel scale.

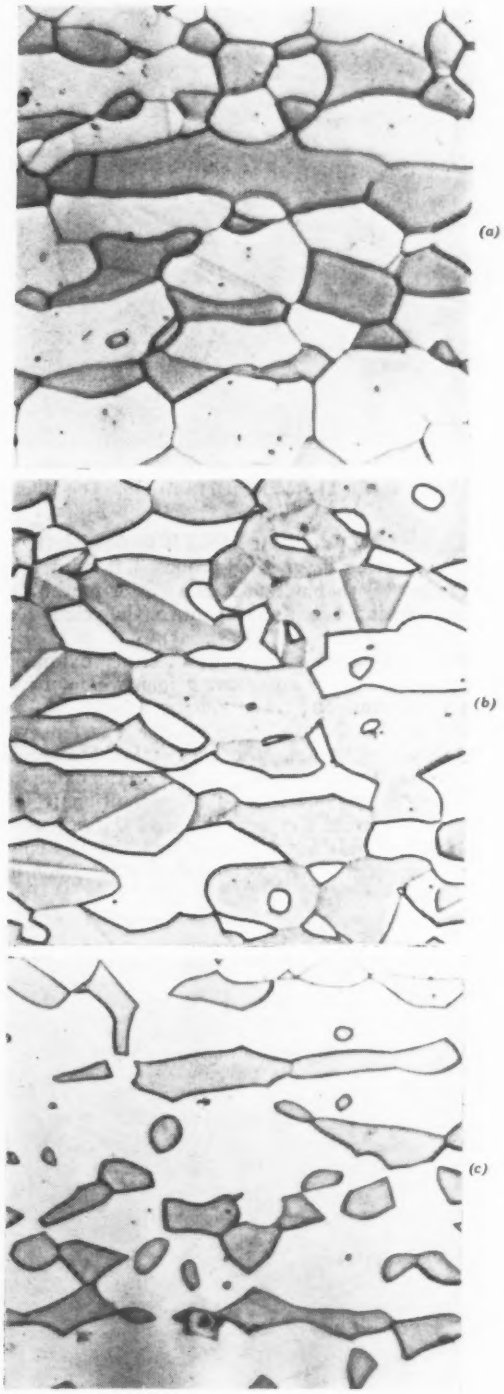
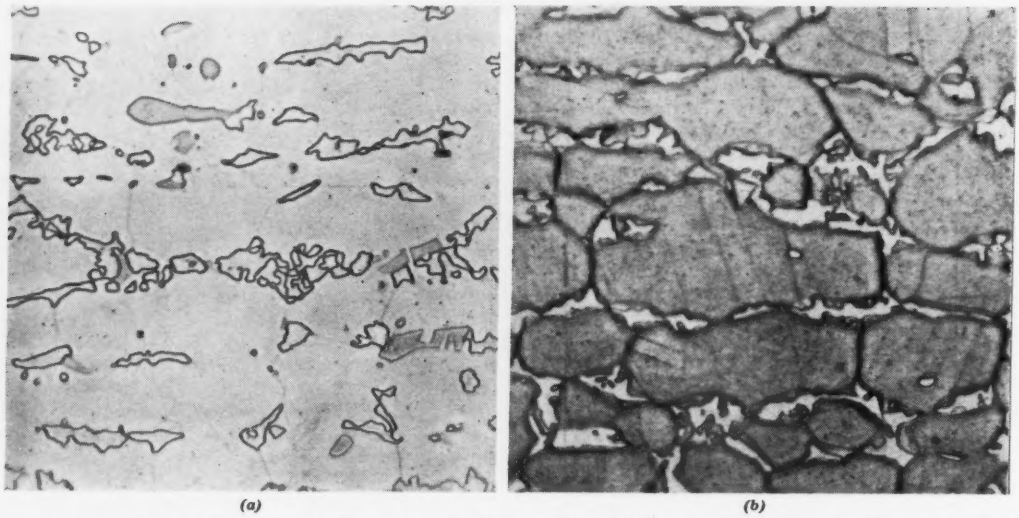


Fig. 2—18–8 Mo–Ti steel, W.Q. from 1150° C. Etched in 20% H_2SO_4 at (*a*) + 1·05 V for 5 min, (*b*) − 0·35 V for 1 h, (*c*) − 0·45 V for 1 h × 1250



(a) (b)

Fig. 3—18–8 Mo–Ti steel, W.Q. from 1150° C + 4 h at 850° C. Etched at (*a*) + 1·05 V for 5 min, (*b*) − 0·35 V for 1 h × 1250

Having now established that it is possible to etch specimens using the method proposed, it is interesting to discuss to what extent it is a better method than the conventional etching reagents or the existing 'electrolytic' methods.

Most etching reagents contain either oxidizing or reducing agents or complexing ions which, in some ways, are equivalent to reducing agents. In other words, most etching reagents are redox systems which probably tend to poise the potential of the specimen being etched at a value depending on the oxidizing or reducing agents present. The conventional etching reagents, therefore, do exactly what the potentiostat does more simply but with less flexibility and control. This is so because the potential of a specimen in an etching reagent is partly dependent on the rate of etching and is, therefore, only very approximately kept constant by the redox system in duplex or multiphase alloys. In these cases the situation becomes very complicated and there is every reason to believe that a phase of a given composition may etch at vastly different rates depending on what else is present in the alloy. This effect becomes very obvious when attempts are made to etch specimens made from a number of alloys in electrolytic contact with each other.

This difficulty is largely avoided with the potentiostat and, within reason, a phase of any given composition should be unaffected by other phases present and behave similarly whether it is the majority or the minority phase. There are two other possible advantages to the use of the potentiostat, namely, that a valve voltmeter can be used to measure the potential during the etching and an ammeter to measure the polarizing current. This means that not only can a given phase be etched in an alloy but that, within

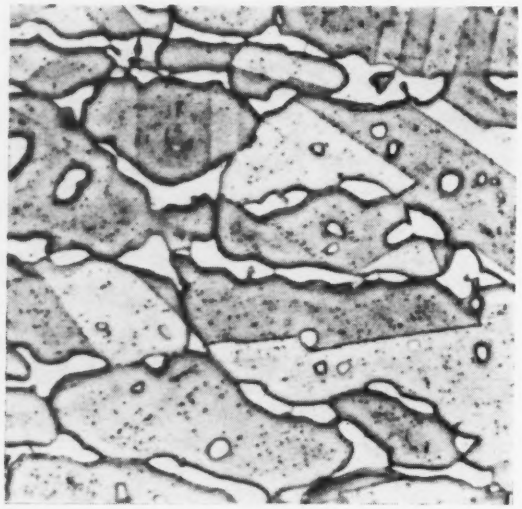


Fig. 4—18–8 Mo–Ti steel, W.Q. from 1050° C + 6 days at 850° C. Etched at − 0·35 V for 1 h × 1250

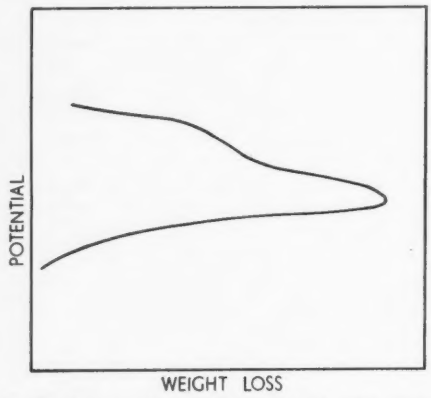
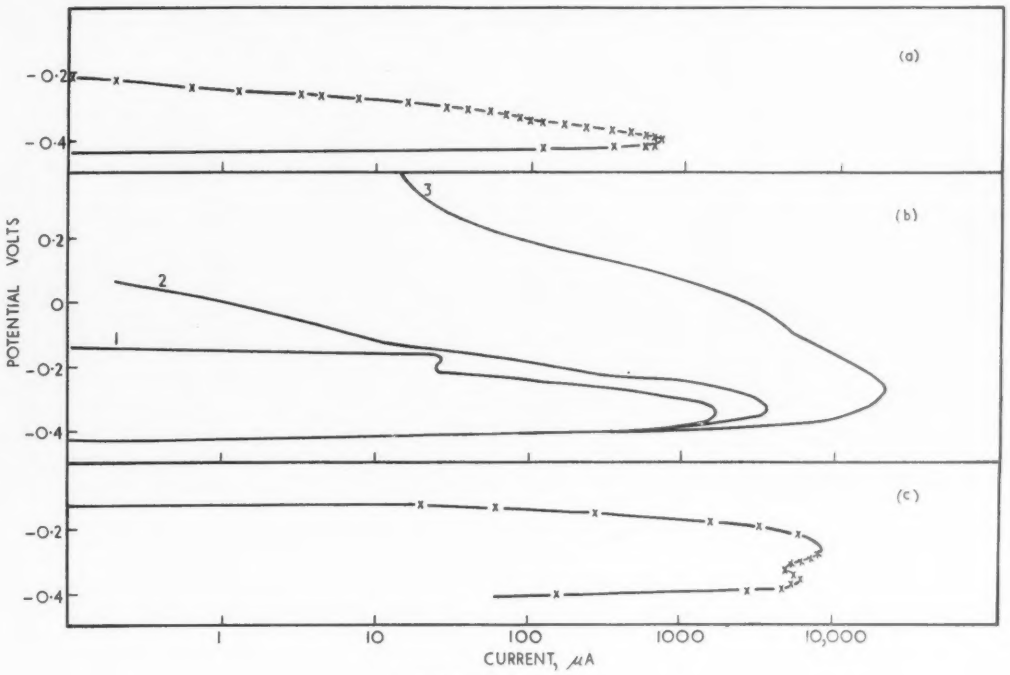


Fig. 5—Diagrammatic weight-loss/potential curve for a steel containing regions comparatively low in chromium



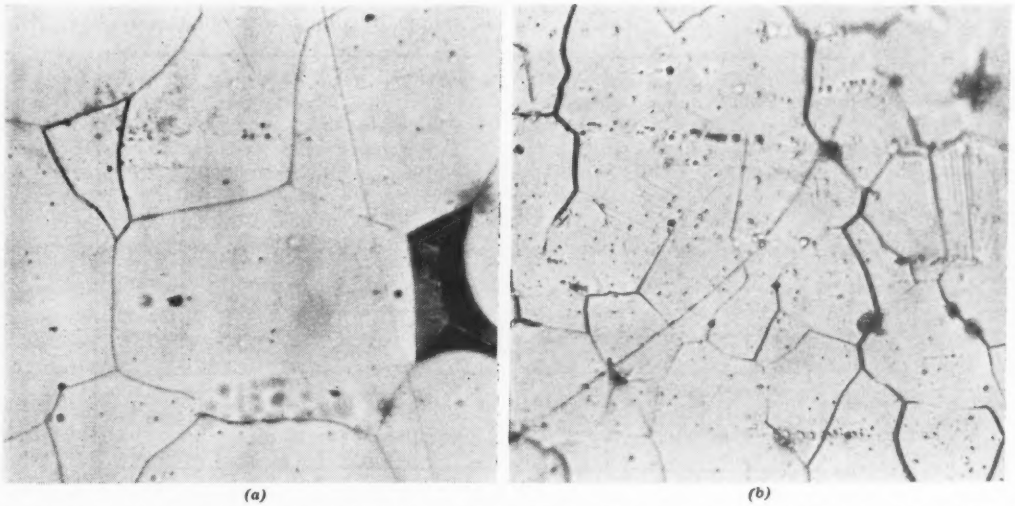
(*a*) W.Q. 1050° C
(*b*) 1. A.C. 1050° C
2. W.Q. 1050° C + 1 h 550° C
3. W.Q. 1050° C + 14 days 550° C
(*c*) W.Q. 1050° C + 6 weeks 650° C

Fig. 6—Potential/current diagrams for 18–8 steel

reason, it should also be possible to say whether it has exactly the same etching characteristics as it has in some other alloy previously studied. This may be useful if it is desired to know whether or not it has the same composition. The advantages of being able to measure currents are discussed in the next section.

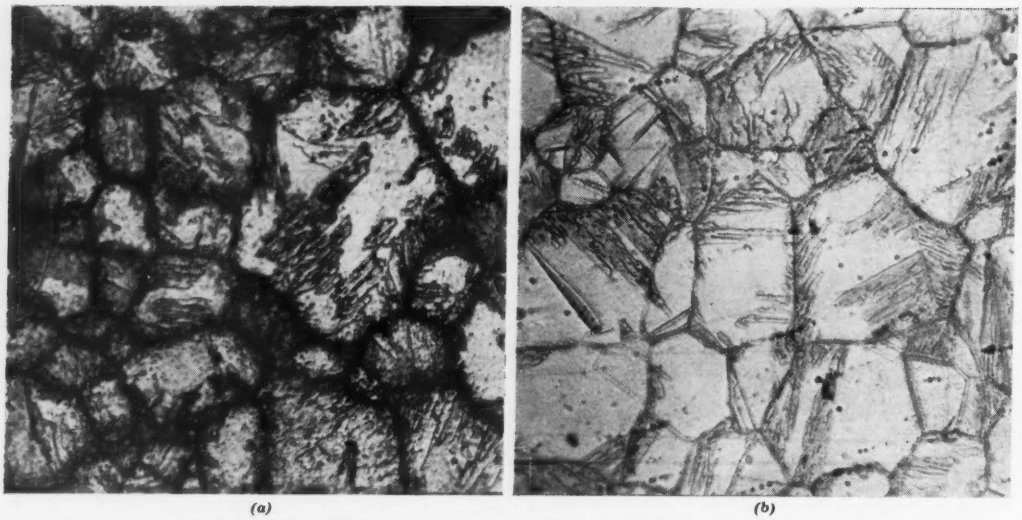
DETECTION OF MINORITY PHASES

The metallographic study of certain precipitation mechanisms is difficult and it may often involve electron microscopy. The precipitation of carbides at the grain boundaries of the 18–8 Cr–Ni steels which is known to lead to intercrystalline corrosion is such a



(*a*) (*b*)

Fig. 7—18–8 Cr–Ni steel, W.Q. from 1050° C + 1 h at 650° C. Etched at − 0·15 V for 1 h: (*a*) × 1250, (*b*) as (*a*) after slight bending, × 500



(*a*) (*b*)

Fig. 8—18–8 Cr–Ni steel, W.Q. 1050° C + 4 weeks at 650° C, and etched at (*a*) − 0·4 V, (*b*) − 0·5 V

case.[8] The more or less universally accepted view is that a region near the grain boundaries is depleted in chromium and that the corrosion resistance of the alloy in this region is therefore lower than elsewhere.[9]

If this is the correct explanation—and it certainly appears to be a reasonable one—a steel containing a small quantity of chromium-poor material may be expected to give a weight-loss/potential curve which is the sum of two slightly displaced curves and, therefore, the 'loop' which occurs at slightly negative potentials might be expected to have the general form shown in Fig. 5. Since, as stated before, there is some difficulty in observing under a microscope the changes which occur during precipitation treatments, this change in the curve presents an additional method for study.

For the present purpose it is time-consuming and unsatisfactory to establish the weight-loss/potential curve, for reasons which will be stated below. On the other hand, a very closely related curve, obtained by plotting the current supplied by the potentiostat against the potential, can be drawn easily, and the relation between the two types of curve has been discussed elsewhere.[2]

In the present work the technique was to use 18-gauge sheet specimens of 8 cm² and immerse them in the solution with the potentiostat set at about + 0·5 V. A constant-speed motor was then started which altered the setting of the potentiostat so that the potential fell at a rate of about 0·4 V/h. The steel used had the following composition:

C, %	Si, %	Mn, %	Cr, %	Ni, %
0·10	0·76	0·77	17·94	7·8

and some of the results are shown in Figs. 6*a–c*.

In the water-quenched condition (Fig. 6*a*) the curve is simple, denoting a single-phase alloy with no

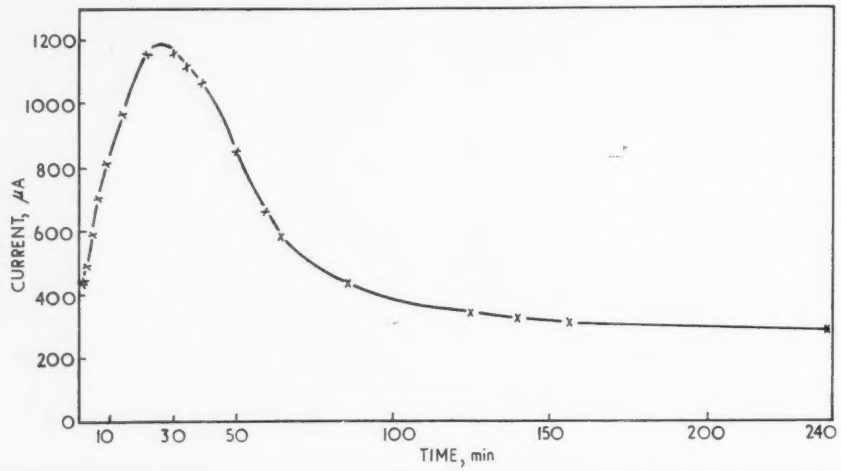


Fig. 9—Current time curve at − 0·15 V for 18–8 specimen aged at 550° C for 14 days

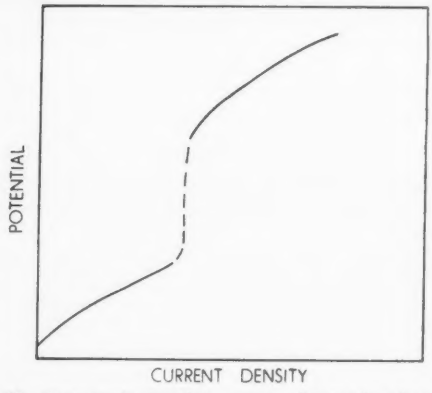


Fig. 10—Current/potential curve obtained when the current is arranged by means of a system of resistances

precipitation. If the alloy was air-cooled from 1050° C, there was a slight indication that some lower-chromium regions were present (Fig. 6*b*) and the amount of this lower-chromium material increased if the specimen was aged at 550° or 650° C for certain periods (Fig. 6*b*). The presence of precipitate was not detected by conventional means in the A.C. 1050° C condition, but was detected in the specimen aged at 550° C for 1 h by using electrolytic oxalic acid etching.[10]

After long periods of ageing at 650° C (4–6 weeks) the steel recovered most of its initial properties, as shown in Fig. 6*c*.

The current/potential curves, therefore, provide a method of following the precipitation mechanism. It is possible to detect precipitation at a very early stage, and to show when diffusion of chromium into the depleted zone has, more or less, restored the properties of the alloy.

At those potentials at which currents were found only with aged alloys, the corrosion was confined, as might have been predicted, to the grain boundaries (*see* Fig. 7*a*, which shows one of the specimens etched at − 0·15 V for 1 h). The attacked region, which presumably is the chromium denuded layer, is extremely thin, but the attack has penetrated sufficiently to allow a small grain to fall out. On slightly bending the specimen it was obvious that this type of attack had occurred everywhere (Fig. 7*b*). The exact interpretation of the double peak in the

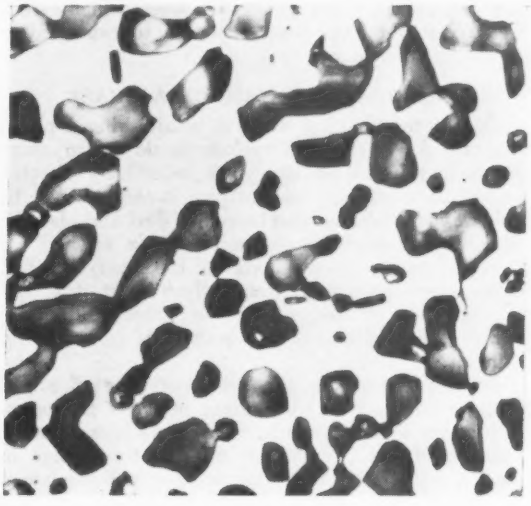


Fig. 11—33–11 Cr–Ni steel, etched at − 0·35 V in 10% HNO_3 for 16 h

overaged specimen (Fig. 6*c*) requires more study, but it is interesting to note that among other things the treatment has caused part of the austenite to transform to martensite, as shown in Figs. 8*a* and 8*b*, and that the austenite and martensite etch at two slightly different potentials. It may be that this explains the double peak but there are other possibilities.

At the start of this section it was stated that weight-loss measurements were unsatisfactory in this case. The reason for this is that even in the worst cases only a few milligrammes of steel are actually dissolved by the time the steel has been fully disintegrated into grains. The current at the potentials at which the grain boundaries are attacked tends to fall with time, as shown in Fig. 9, but with short-duration experiments, by measuring currents with a microammeter, micrograms of grain-boundary material can be easily detected.

One last point on intercrystalline corrosion is worth mentioning. The copper-sulphate/sulphuric-acid solution (2N.H_2SO_4 with 10% copper sulphate), very often used in practice to detect a susceptibility to intercrystalline corrosion, is such that it poises

Table I

ANALYSIS OF STEEL DISSOLVED DURING ETCHING AN 18–8 STEEL AT FIXED POTENTIALS

Potential	1050° C, W.Q. Condition					1050° C, W.Q. + 10 days 550° C				
	Cr found, mg	Ni found, mg	Fe found, mg	Cr, %	Ni, %	Cr found, mg	Ni found, mg	Fe found, mg	Cr, %	Ni, %
+ 1·05	11·1	5·10	44·9	18·2	8·3	54·6	25·5	234·2	17·4	8·1
+ 0·50	0·20	*	*	—	—	0·030	0·04	0·30	8·1	10·8
+ 0·20	—	—	—	—	—	0·010	*	0·21	—	—
− 0·05	0·003	*	*	—	—	0·43	0·53	5·31	6·86	8·45
− 0·20	—	—	—	—	—	16·7	8·2	73·0	17·98	8·83
− 0·225	5·1	2·3	23·2	16·7	7·5					

* Quantity too small for analysis

the potential of the shot at values which, from Fig. 6*b*, might have been expected to cause intercrystalline corrosion.

CHEMICAL ANALYSIS OF A PHASE

One of the simplest ways of establishing a phase diagram for a complex system would be to make alloys in the two-phase regions, selectively dissolve one of these phases, and analyse it chemically. In this way the tie lines can be established and also the positions of single-phase limits. This method, or the alternative which involves the analysis of a residue, has been used frequently,[4, 5] but it is not always easy to find a suitable solution and one which will not make the analytical work unduly difficult.

It seems probable that the potentiostat might help in this type of work, since many of the possibilities are lost without it. This is so because most other electrical circuits are difficult to arrange in such a way that the middle range of potentials can be studied. The potential/current curve drawn with an ordinary resistance in circuit, for example, is of the type shown in Fig. 10, and sometimes wild oscillations occur over the middle portion of the curve for obvious reasons.

An example of the use of the potentiostat for this purpose is given in Fig. 11, which shows the selective corrosion of the austenite of a 32·52% Cr, 10·88% Ni steel after etching at $-0{\cdot}35$ for 16 h in 10% HNO_3. This acid was chosen because it made the analysis easier than sulphuric acid and because it is an acid in which the natural corrosion of both phases is negligible. If, therefore, any grains of delta had become dislodged they would not have dissolved. The actual analysis figures for the austenite so dissolved were 23% Cr and 13·7% Ni but no claim to great accuracy is made, since it is not certain that the attack was, in fact, fully selective.

As a matter of interest, in Table I some analysis figures are given for the material corroded during experiments at fixed potentials with the steel used in the experiments described in the previous section. Because of the very small quantities of material found in the solution, the accuracy of these results cannot be very great, but there is no doubt that the grain-boundary material is chromium-poor.

SUMMARY

It is shown how it is possible with a potentiostat to carry out controlled etching of metallographic specimens.

Additional information may be obtained by measuring the currents supplied by the potentiostat and it is shown how, for instance, the small traces of material at grain boundaries which cause susceptibility to intercrystalline corrosion can be detected in this way. If the potentiostat technique is coupled with analytical work, it is shown how it is possible to analyse the material at the grain boundaries of susceptible steels or a phase of a duplex alloy.

Acknowledgment

The author wishes to express his thanks to the Directors of Thos. Firth and John Brown, Ltd., for permission to publish this paper.

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OBITUARY

Sir John Craig, C.B.E., D.L.

SIR JOHN CRAIG, C.B.E., D.L., President of The Iron and Steel Institute from 1940 to 1942, and Honorary President of Colvilles Ltd., died at his home in Wishaw, Lanarkshire, on 1st February, 1957, at the age of 82.

He spent his whole business life with Colvilles Ltd., joining the company in 1888 in the offices at a salary of 5*s*. a week. His promotion was rapid, and in 1910 he was made a Director of the Company. Six years later he was elected Chairman of the Board, and he held that position until 1956. During that period Sir John saw the Company grow from a family business into the major steel-producing concern it is today. It was under his guidance that the Company weathered the difficult period between the wars, and that the post-war expansion and replanning were carried out.

His services during the First World War were recognized by the award of a C.B.E. in 1918, and he was knighted in 1943 for his work during the Second World War. Sir John served on the boards of a number of other companies, including Harland and Wolff Ltd. and the Bank of Scotland. He was a Past-President of the National Federation of Iron and Steel Manufacturers, and was for some years a member of council of the Federation of British Industries. He was elected an Honorary Member of The Iron and Steel Institute in 1956, and the Honorary Degree of Doctor of Laws was conferred upon him by Glasgow University in 1951.

Tenth Chemists' Conference

ASHORNE HILL 2nd–4th OCTOBER, 1956

FOR THE TENTH in its series of annual conferences, the Metallurgy (General) Division of the British Iron and Steel Research Association chose Harrogate as a centre. That the move north met with approval is indicated by the fact that in his opening remarks the Chairman, Dr. E. Gregory of Edgar Allen and Co., Ltd., recorded an attendance of 180—the highest ever. The conference, held from 2nd to 4th October, 1956, at the Old Swan Hotel, broke new ground in devoting the whole of one session to the subject of sampling for analysis. The papers presented and the speakers were:

Sampling

" An introductory talk on the technique of sampling", illustrated by an I.C.I. film	Mr. W. T. Elwell (Imperial Chemical Industries, Metals Division, Ltd.)
" Sampling with special reference to iron ore "	Dr. G. V. James, M.B.E. (Rudd Thompson and Partners)
" Sampling problems in spectrographic analysis "	Mr. J. H. Oldfield (Admiralty Materials Laboratory)
" Sampling of ferro-alloys "	Dr. W. Sachs (London and Scandinavian Metallurgical Co.)

Analytical Methods and Safety Precautions

" Some analytical applications of ethylenediaminetetra-acetic acid "	Mr. G. W. C. Milner (United Kingdom Atomic Energy Authority)
" A non-destructive microchemical method for sorting steels "	Mr. W. R. Nall (Bragg Laboratory, Naval Ordnance Inspection Department)
" Safety in the chemical laboratory "	Dr. L. J. Burrage (Imperial Chemical Industries, General Chemicals Division, Ltd.)

Corrosion

" Quantitative research on metallic corrosion "	Dr. U. R. Evans, F.R.S. (University of Cambridge)

Opening the conference, the Chairman said that the work of the Methods of Analysis Committee of B.I.S.R.A. had gone ahead with undiminished vigour. He did not give, as in previous years, a detailed review of the year's work by the Committee, but he drew attention to four reports published in the *Journal of The Iron and Steel Institute* and to the preparation of further parts of B.S. 1121, *Methods for the Analysis of Iron and Steel*, of which thirty-five parts had been issued. It was intended, Dr. Gregory said, to condense these into one volume, which he predicted would be the most practical manual on the analysis of iron and steel ever published.

Paper MG/D/46/57 of the British Iron and Steel Research Association, received on 17th January, 1957.

FIRST SESSION: SAMPLING

Technique of Sampling

Introducing what he called 'a very controversial subject,' Mr. **W. T. Elwell** referred to the thousands of tons of raw materials used annually by industry, and the need for accurately checking their quality. The sample was of great importance; an analysis was valueless or even positively misleading if the composition of the original sample did not accurately represent that of the bulk. He gave two criteria for the selection of samples:

(i) The properties of the sample should correspond as closely as possible to those of the parent material as a whole

(ii) If samples were taken several times, the average of the samples should approach more and more closely to the bulk, i.e. the sample should be free from bias.

It was all but impossible to devise a sampling procedure acceptable to both producer and consumer. The 'correct' procedure was largely a function of the material to be sampled. Consideration had to be given to such factors as the value of the material, its bulk, nature, properties, variability, and the degree of precision required.

The theory of sampling was based on statistics, but many of its practical aspects could only be mastered by experience. There were two distinct methods of taking samples: random sampling and representative sampling.

The theoretical basis of random sampling was that every portion of the bulk had an equal chance of being represented in the sample. The method of taking random samples was in no way connected with the properties of the components. It was assumed that all possible choices were equally probable, and it was essential that this condition should be fulfilled.

In taking a representative sample, a portion was removed in a systematic way from a number of real or imaginary sections so that each increment represented

Table I

DETAILED ANALYSIS OF A SAMPLE OF MARQUESADO SPECIAL ORE (1947)

Showing size and composition of each sieve size

	Particle Size	% of Cargo	Iron (Fe), %	Silica (SiO_2), %	Phosphorus (P), %
Large	Over 8 in.	12·40	39·1	1·60	0·007
	5–8 in.	7·75	43·4	2·65	0·007
	2–5 in.	10·85	48·0	1·90	0·008
Rubble	1–2 in.	22·01	47·7	2·15	0·010
	½–1 in.	8·99	52·4	2·20	0·015
	¼–½ in.	3·80	57·0	2·40	0·016
Small	⅛–¼ in.	11·40	59·4	2·60	0·015
	1/16–⅛ in.	6·65	59·2	2·60	0·015
	Passing 1/16 in.	16·15	57·0	3·55	0·016

Overall composition: 31% lump, 31% rubble, 38% small.
Composite result: 51·1% iron.

a portion of the bulk. This method was used when systematic variations in the material were suspected; when there were variations it was more precise than random sampling.

Other important aspects of sampling referred to by Mr. Elwell were size, bulk ratio, size/weight ratio, state of division, visible foreign matter, the presence of hygroscopic or easily oxidized materials, and storage. Training of the sampler was also mentioned.

Film

The film *The Technique of Sampling* was made by the I.C.I. Film Unit in collaboration with the Analytical Chemists' Committee of I.C.I., consisting of Divisional Chief Analysts. The purpose of this film is to show some of the methods used by the company, most of whose sampling problems concern solids. Three typical examples are shown in order of increasing complexity: 'nitrate of soda,' limestone, and coal, the last-named providing what are probably some of the most difficult and controversial sampling problems encountered in industry.

Special aseptic techniques used for sampling penicillin are also illustrated in the film.

Sampling Iron Ore

This film was followed by a paper on sampling with special reference to iron ore, presented by Dr. **G. V. James** of Rudd Thompson and Partners. He began by pointing out that a sample weighing about 100 g might represent a consignment of 10,000 tons of ore; it was therefore of the greatest importance that the sample should be thoroughly representative. It should contain the correct proportions of pieces of ore of different sizes, together with the correct proportions of any foreign matter and impurities that might be present. It followed that trained samplers should be responsible for the work; the vital operation of sampling could not be satisfactorily carried out by any casual worker who might be available.

It was difficult to obtain a truly representative sample because iron ores might be heterogeneous in two ways: impurities might not be uniformly distributed, and the size of the particles might vary. Table I shows how composition can vary with particle size.

Mechanical methods of sampling had been advocated, but Dr. James pointed out that such devices as sweeping arms on conveyor belts might leave smaller particles behind, with serious effects on the final result.

In practice, the samplers representing the sellers and the purchasers had to agree on a compromise procedure. Agreement on methods of taking representative samples is needed because the distribution of an impurity could be very uneven.

The size of a representative gross sample depended on the size of the cargo, the variability of the cargo, and the accuracy expected of the ultimate analysis. This accuracy would in turn depend on the purpose for which the sample was taken.

Contracts usually contained a penalty clause through which a price penalty was incurred if the ore supplied contained less than an agreed amount of a defined active ingredient. Sometimes a second penalty might be introduced for the presence of an inactive or harmful ingredient.

Certain principles should be followed when taking samples. If the shipment were uniform it was better to take several small increments than fewer larger ones. A gross sample representing a heterogeneous ore might be made up of as many as 300 increments.

In sampling from ships' holds, increments of about 1 l. (1½ pints) in volume were removed with a scoop or shovel during unloading, care being taken to ensure that the sample contained the correct proportions of large, rubble, and small size grades, particularly of the last-named. If the relative proportions of the various size grades changed as loading went on, the sampler would alter his sample accordingly. Increments could be taken from a bucket or grab in the hold, from loaded wagons, or from conveyor belts during and after unloading. Particular care was necessary in taking samples from conveyor belts because of segregation during movement. Samples should be taken in a regular pattern: from the sides and middle of different wagons if the ore were in layers; from apex to base of a mound, descending spirally.

As soon as it was taken, each increment should be set aside in an air-tight container to prevent contamination and loss of moisture. It was a good plan to take two or three samples concurrently and to test them separately; if they had been taken correctly the results would be in substantial agreement.

Sampling in mines was very difficult; the method used depended on the particular purpose in view. In the U.K. the material was usually sampled when it was unloaded at the surface. The method to be used in sampling new mines or deposits depended largely on three factors: the form of the deposit, the distribution of the mineral, and the structure of the ore.

Dr. James then went on to deal with the reduction of the gross sample weighing several tons to a suitable bulk. He again emphasized the need for storing the increments under proper conditions so that they did not become contaminated or lose moisture. The gross sample should be thoroughly mixed and crushed to ⅛ in. and then coned, layered, and quartered. It was important that the apex of the cone should be truly centred on the base; if not, the proportions of the large and small particles might be affected by discarding opposite quarters. The discarded quarters of the cone could be used for moisture determination. The sample was then crushed, sieved, and reduced in size by coning, layering, quartering, crushing, mixing, etc., until a residue weighing about 3 lb was left which would pass a 1/20-in. sieve. Care should be taken during crushing to make sure that segregation did not occur through softer materials being crushed first.

The methods described for sampling ores could be equally well applied to road materials, spent oxide, or other materials; the only reservation necessary concerned the stage at which the moisture samples were taken.

Sampling Problems in Spectrographic Analysis

Mr. **J. H. Oldfield** of the Admiralty Materials Laboratory introduced this subject by explaining the

Table II

METHODS OF SPECTROGRAPHIC SAMPLING

As Received	Initial Treatment	Subsequent Procedure		
Solid metal	Directly	Repeat exposures	Superimposed exposures	Moving sample
	Re-cast	Rods	Disks	
	Milled	Millings	Briquetted	
	Solution	Porous cup	Impregnated graphite	Rotating graphite disks
Powder	Fused	Powdered	Electrode tipped	
	Directly	Powder	Briquette	

need which might arise for modifying the form of the sample taken for spectrographic analysis. Table II shows the forms and the methods used to overcome the problems he discussed.

Various factors affect the choice of method. It was sometimes necessary to ensure that the metallurgical condition of the samples matched that of the standard; recourse could then be had to re-casting. Quantitative spectrographic analysis was based on the use of internal standards; where there was considerable variation in composition, it might be necessary to add a suitable internal standard. Prepared solutions or briquettes could be used for this purpose. There was also the inter-element effect to be considered. Easily ionized elements tended to affect the excitation of those that were less easily ionized. The necessity of providing a buffer element to reduce this effect presented a problem which might be solved by converting the sample into the form of a solution of a briquette.

The choice of a suitable procedure might be influenced by the necessity of eliminating the effects of heterogeneity in the sample. In spectrography the amount of sample used was the amount actually excited, and might be much less than $\frac{1}{2}$ mg. Furthermore, success depended on the use of the internal standard method, and if the sample were heterogeneous the concentration of the internal standard would vary and errors would result. Attempts to overcome the problem of heterogeneity had been made in two ways: by increasing the amount of sample excited (by repeat exposures) and by rendering the sample more homogeneous before exciting it. Of these two methods the second was the ideal, but using it could considerably increase the time required for the analysis.

A completely homogeneous sample could be obtained by re-casting it in some special shape or size, or by taking the sample into solution. The solution could then be excited by being transferred into the energizing source as a mist or spray, or it could be more directly excited by one of several procedures which transported the solution into an electrical discharge without initially vaporizing or atomizing it. Homogeneous samples of refractory materials could be obtained by fusing them, the melt being transferred directly to a suitable supporting electrode or converted into a solution for excitation.

The speaker emphasized that although the sample could be rendered homogeneous by one of the methods indicated above, it did not follow that errors associated with the inter-element effect would thereby be eliminated. These errors might be reduced, but where they were due to large differences in excitation potential, etc., their elimination was rather a spectrographic 'source' than a 'sampling' problem.

Sampling Ferro-alloys

Dr. **W. Sachs** began his paper by explaining that the term 'ferro-alloy' included all metallic addition agents used in making steel and cast iron. The purpose of adding ferro-alloys was either to incorporate an alloying element into the steel or to refine it. Some ferro-alloys, such as calcium silicide and silico-manganese, contained only small amounts of iron; more rarely, even pure metals were used as 'ferro-alloys', for instance, manganese metal and chromium metal. Some ferro-alloys contained two or three alloying elements besides iron, and these acted in different ways.

Whereas most ferro-alloys were paid for according to the amount of alloying element present, some were paid for also according to the presence or absence of other constituents. A typical case was ferro-chromium, for which the price per unit chromium increased with a decrease in the carbon content, so that the carbon content became an essential factor affecting the cost.

Other elements such as silicon, phosphorus, and sulphur (representing deleterious impurities) had also to be checked by sampling and analysis.

It was thus evident that ferro-alloys had to be sampled somewhat differently from iron ore, pig iron, or scrap. Although the quantities of ferro-alloys used in the steel industry were much smaller than the quantities of the bulk raw materials used in steel manufacture, some of them were extremely expensive, costing up to £1700 per ton. Dr. Sachs therefore stressed that the economic factor should be taken into account before deciding on a sampling procedure for such materials. With the more expensive alloys it was particularly futile to save on sampling costs and equipment.

Because ferro-alloys were used to adjust the final composition of the steel bath, it was of the utmost importance that their exact compositions should be clearly established; careful and reliable sampling was essential to achieve this aim.

The analytical methods for many of the components of the ferro-alloys were long and complicated; costly check-repeats could be avoided by proper sampling procedures. In practice, he had found that errors were as often due to incorrect sampling as to mistakes in analysis.

No material could be sampled properly unless something were known about the process by which it had been manufactured. Some ferro-alloys such as the various ferro-silicon alloys, containing 25–95% silicon, were made in continuous processes in large electric furnaces. Others, such as medium and low-carbon ferro-manganese, were made in batches in rather large casts in large electric furnaces. Special alloys, such as ferro-tungsten, were made either in batches in small electric

furnaces, or, more often, by alumino-thermic or silico-thermic reactions in buttons of up to 1 or 2 tons.

In deciding the sampling procedure to be used, it was important to know how the alloy had been made, and perhaps still more important to know what the manufacturer had done in order to make the material homogeneous. It was also important for the consumer to deal with a reliable manufacturer who would himself have used the best possible ways and means to consolidate a homogeneous parcel from up to 20 to 30 casts and to sample it at the same time in the most reliable way. In order to know how much valuable alloy was in his finished product, the maker of ferro-alloys had to apply stringent sampling procedures. Check-sampling a parcel at the customer's works could only be reliable if the consumer or the independent sampler and analyst had the proper equipment and also had special knowledge of the peculiarities of the materials and method of manufacture.

Unfortunately, most ferro-alloys tended to segregate and, still more unfortunately, this tendency applied not only to the impurities, but also to the valuable alloying element itself. This difficulty could be overcome to some extent by sorting an individual production batch into different grades according to appearance, but the application of this method was limited and would increase the cost of producing a homogeneous material. Segregation occurred in practically all ferro-alloys; some segregations were visible to the naked eye, but others could only be detected by chemical analysis.

Experience and common sense would determine how large a primary sample had to be and how it could best be taken. For example, a 10-ton consignment of high-carbon ferro-chrome, supplied in first size and packed in barrels or drums, could be sampled by opening one out of ten containers and spreading their contents over a clean steel floor in a layer not more than 5 or 6 in. thick. This sample should then be reduced by coning and quartering; strictly speaking, it should be reduced in size between each coning and quartering operation. Eventually, the final sample should pass a 72-mesh sieve. Great care should be taken that no part of the sample was discarded because it would not pass a given sieve.

For alloys such as low-carbon ferro-chrome, which could not be crushed and were usually supplied in fairly large lumps, the procedure was as follows: at least 2% of the containers should be opened and at least five big lumps taken out of each. These lumps should be drilled so as to give representative cross-sections of the various pieces. The drilling should be well mixed, coned, and quartered, and the sample then be crushed to a finer size if possible, much in the same way as for high-carbon ferro-chrome. Ferro-tungsten should, as a rule, pass a 100-mesh sieve, ferro-vanadium only a 40–50-mesh sieve, ferro-chrome, ferro-molybdenum, ferro-titanium, and ferro-niobium were somewhere in between.

The standard methods published by the American Society for Testing Materials gave a good survey of equipment. Strong jaw crushers were used for crushing materials to sizes down to approximately $\frac{1}{4}$ in. The crushing plates of such a machine must be made of hard and abrasion-resistant steels. For further reduction in size, roll crushers were recommended, although they were not used everywhere in Europe. The mortar and pestle must also be made from properly hardened alloy steel; the upper part of the pestle should be slightly softer than the remainder, and the surfaces should be well polished. Mechanically operated pulverizing equipment could be used, but such equipment very often exerted too much force, so that more plates were formed.

The use of riffles or Jones dividers was preferable to hand methods for dividing samples. Special care had to be taken in this operation, as well as in crushing and sieving, to reduce loss of dust which might falsify the sample.

Sampling ferro-alloys at the manufacturer's works clearly offered many advantages. Most ferro-alloys had to be crushed, and mixing, coning, and quartering could be replaced at least partly by sampling the material as it passed through the crushers at the works; if this were carefully done, it was the most satisfactory way of obtaining the right proportion of coarse and fine material in the primary sample.

Some ferro-alloys were extremely brittle (e.g. low-carbon ferro-manganese and ferro-silicon); others, like ferro-tungsten and high-carbon ferro-chrome, were difficult to crush and required specially strong equipment, whilst there were a few, especially low-carbon ferro-chromium, that could not be crushed at all. Samples had then to be taken by drilling.

Drilling should be done in such a way that the hole or holes extended through the cross-section of the whole cast of metal, because, owing to segregation, different layers might differ considerably in chemical composition. A high-speed steel drill should always be used.

Where crushing was possible, small variations in chemical composition might result in very different physical behaviour. For example, one batch of ferro-niobium-tantalum could be so hard as to defy crushing and another batch differing only slightly in composition might break quite easily. Still worse, very brittle and very tough zones could be found in the same batch. The haphazard method of knocking off pieces with a hammer was therefore very dangerous for sampling ferro-alloys, because the workman might succeed in knocking off pieces of one particular zone, but not off the other much tougher zone; the pieces he collected would, of course, form an entirely unrepresentative sample. The human element should therefore be excluded as far as possible from sampling procedures.

Some alloys, such as tungsten melting base, could neither be crushed nor drilled in the as-cast condition, and a cast sample or some lumps had to be annealed to make drilling possible.

If the sample were ground too fine, certain alloys, such as ferro-silicon and ferro-titanium, might be oxidized. It was not advisable to include slag in the sample of the ferro-alloy.

Discussion

The discussion on this session was opened by a speaker who referred to the difficulties encountered in sampling indigenous ores and described the methods which had recently been used for taking samples from depths of up to 58 ft in the Scunthorpe ore-field, where reserves had been proved in bores and trial holes. When mining began samples were taken from the face of the working, as described by Dr. James. The advantage of having this information quickly was that the blast-furnace staff were able to adjust the burden according to the composition of the ore. In sampling sedimentary iron ores, great care was needed, especially in reducing the sample to powder.

A second contributor to the discussion referred to the loss of moisture during the final preparation of the sample and gave details of some experiments that had been carried out on ores. A 4-cwt sample had been crushed, coned, and quartered to sizes from $\frac{1}{2}$ in. to 30-mesh. The fraction from $\frac{1}{2}$ to $\frac{1}{4}$ in. lost 8% of its moisture; the $\frac{1}{2}$–$\frac{1}{4}$ in. fraction lost 20%. Had the sample been crushed to $\frac{1}{8}$ in. in one operation, the loss of moisture might have been less, however.

Dr. James commented that it might be necessary to dry the ore before crushing it. He had himself found evidence of loss of moisture on crushing.

Referring to the papers presented by Dr. James and Mr. Elwell, another contributor commented that it was surprising that, although standard methods were available for coal, there were none for iron ore. It was, he said, very difficult to decide the proportions of lump and rubble in a consignment. What happened when two or three experienced samplers made independent assessments of the size and then took samples? In sampling lumps there was a tendency towards loss of accuracy, especially where 'fines' were concerned. Was it possible to devise a sampling scheme in which lump, rubble, and fines were sampled and analysed separately and the results combined to give the final analysis?

Advocating the use of mechanical sampling equipment, another speaker suggested that it would be easier to design a mechanical arm, for example, to sweep the required quantity of material from a conveyor belt than to train the necessary number of samplers. The present-day rate of discharge of ships was so great that samplers did not see more than a fraction of each cargo. Representative sampling was, at best, very inadequate.

In his reply Dr. James agreed that it was difficult to obtain satisfactory people for the work of sampling. He thought that four or five years or more was needed to train a sampler. Experience was an essential part of the sampler's equipment. At his company samplers began sampling under the supervision of a trained man. He was not convinced of the superiority of mechanical sampling; it would be very difficult to devise suitable equipment for conveyor belts with raised edges for example. Table III showed the sort of results that were obtained when three samplers worked independently.

Another speaker, referring to Dr. Sachs's paper, said that it was a good idea for the laboratory to be responsible for taking samples if specialist staff were not available. It was impossible to sample ferro-alloys properly without making fines, which was unpopular. Because of this a smaller amount had often to be taken.

Commenting on the other points raised in the discussion, Dr. Sachs said that some analysts preferred steel mortars to agate; with a properly hardened alloy steel there was less abrasion. He recommended that sampling should be done at the manufacturer's works rather than at the buyer's, unless the buyer had the proper equipment. No rules could be laid down for the percentages to be taken; the relative size of the sample depended on the value of the material, and was a matter of commonsense.

Another contributor to the discussion said that it was useless to improve analytical methods without improving methods of sampling. There was apparently no accurate method available for moisture sampling, and he felt that research should be done on the problem—perhaps by B.I.S.R.A.

Dr. James welcomed this comment and said that he was usually less sure of the method of sampling than of the analytical work. He thought that the time was ripe for further research on sampling methods, although speed often militated against refinements in sampling techniques.

SECOND SESSION: ANALYTICAL METHODS AND SAFETY PRECAUTIONS

Ethylenediaminetetra-acetic Acid

Introducing the paper by Mr. **G. W. C. Milner** on analytical applications of this acid, Mr. B. Bagshawe, who took the chair for this session, said that the steel industry had not yet utilized E.D.T.A. (as it was commonly known) to the fullest extent.

Mr. Milner said that E.D.T.A. was fast becoming one of the more important analytical reagents. It was being used in volumetric analysis for the determination of such

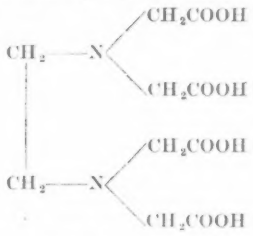
Table III

IRON CONTENT OF REPLICATE SAMPLES

Type of Ore	A, %	B, %	C, %
Kelougha	51·20	50·94	50·90
Djerissa	54·50	53·87	54·11
Kiruna	62·20	66·80	66·75
Kiruna	63·13	62·70	62·74
Oued Zem	44·68	44·07	43·86
Wabana	50·19	49·47	49·10
Wabana	51·15	50·50	51·00
Wabana	50·87	49·79	50·70
Wabana	51·80	51·25	51·20
Wabana	51·35	50·80	50·76
Wabana	51·55	51·00	50·72

elements as thorium, aluminium, and zirconium, which in the past had presented difficulties. It was also finding uses as a masking agent to prevent undesired precipitation and to suppress interference.

He described the complexones as compounds derived from ammonia, of which E.D.T.A. is one of the few that have found practical applications.



He went on to refer to the chelating effect of the E.D.T.A. group and the formation of five-membered rings, which accounted for the great stability of the complexes formed by E.D.T.A. Although the acid was fairly soluble in water, its sodium salt was usually employed.

The complexes formed by E.D.T.A. with the metal ion were in the ratio 1 : 1, irrespective of the charge on the metal ion. Hydrogen ions were liberated in the complexation; a buffer had therefore to be added if the pH value of the solution were to be kept constant. E.D.T.A. was not a very selective reagent and would combine with many metals.

The development of suitable indicators for use with E.D.T.A. had been difficult. Organic or inorganic compounds were used to form coloured complexes with the metal ions which were broken down on titration with E.D.T.A. The titration could be compared with that of a strong acid with a strong base. There was a sharp change in pM (M denoting the metal ion) at the end-point, which could easily be detected if the logarithm of the reaction constant K were equal to 10 or more.

Thus, with bismuth an iodide complex could be used to detect the completion of the titration, the colour being discharged at the end-point. Ferric salicylate could be used similarly for iron. Coloured lakes formed with alizarin were used for other metals (e.g. thorium). Back-titration had to be resorted to in other instances. Electrical methods were also being investigated, particularly in the U.S.A. There was considerable activity in seeking new methods of detecting end-points.

Mr. Milner went on to describe the analytical procedures used for determining various metals with E.D.T.A. For determining aluminium excess E.D.T.A. was first added. The solution was then buffered to pH 4 and salicylate added, and then back-titrated with ferric iron. There were quick methods of separating aluminium from other constituents; for example, the precipitation

of aluminium as its insoluble benzoate could be used for copper-based alloys. The presence of titanium and zirconium, which would be precipitated as benzoates, presented a difficulty in silicate analysis. He thought that the most promising line of progress for the future would be the use of ion-exchange resins in place of benzoate precipitation.

The method described for aluminium could also be used for the determination of zirconium. The end-point was, in fact, better, because the complex formed by E.D.T.A. with zirconium was more stable.

In the determination of zirconium, precipitation with mandelic acid could be used to separate it from other constituents. This had several advantages, as precipitation was carried out in hydrochloric acid or $HClO_4$ solutions. The procedure was to dissolve the sample in nitric and hydrofluoric acids, evaporate to fumes of perchloric acid, and then carry out the precipitation. The zirconium mandelate precipitate was dissolved in ammonium hydroxide before titration with E.D.T.A. Another procedure was to effect the precipitation of zirconium as barium fluozirconate. This method had the advantage that zirconium could be determined in the presence of tantalum and niobium. The method was satisfactory in the presence of titanium, uranium, molybdenum, lead, iron, and copper. Aluminium and bismuth interfered, however.

Zirconium could also be determined directly in the presence of uranium when the end-point of the titration was determined with a cheap absorptiometer. Bismuth, tin (stannous and stannic), and titanium interfered. Mr. Milner also outlined titration methods using E.D.T.A. for bismuth and gallium.

Passing on to the use of E.D.T.A. as a masking agent, he referred to its value in the determination of copper in non-ferrous and ferrous alloys. Interference by bismuth could be eliminated by adding cyanide. In determining aluminium in ferrous materials, the aluminium 8-hydroxyquinoline complex was extracted with chloroform.

For determining uranium in alloys the metal was precipitated as its phosphate at about pH 5 in the presence of E.D.T.A. and then redissolved in hydrochloric acid. The solution was passed through a lead reductor to reduce the uranyl to the uranous ion, which was then titrated with standard ceric sulphate.

Discussion

Mr. Milner was asked whether any research had been done to make E.D.T.A. more selective and whether excess of ammonium salts interfered with the titration of nickel with E.D.T.A.

Asked what factors affected the precipitation of zirconium with mandelic acid, Mr. Milner replied that it was important that the acid conditions were correct. If zirconium were precipitated from solutions stronger than 5N, the precipitate could be dried and weighed directly. The method was very reliable in the absence of sulphates.

Non-destructive Method for Sorting Steels

The second paper in this session was presented by Mr. **W. R. Nall** of the Bragg Laboratory, Naval Ordnance Inspection Department, Sheffield.

Referring to the history of identification tests, Mr. Nall spoke of the work published in 1943 by Evans and Higgs, who described ' spot ' tests applied directly to the surface of the metal with an 18–8 chromium steel, when diphenyl carbazide gave a more or less fugitive colour. A red stain was similarly obtained on nickel-bearing steels with dimethylglyoxime.

A fresh impetus was given to semi-quantitative micro methods when Weisz described his ring oven in 1954. Mr. Nall demonstrated the operation of this apparatus, using a ring oven built in Sheffield to study the technique. He used an electrographic sampling technique with a 5·5-cm filter paper.

He went on to refer to the work of Stephen. In his first paper on the use of the Weisz ring oven, Stephen had described the analysis of three alloys: cupro-nickel, a copper–nickel–iron alloy, and Invar. In his second paper, Stephen described methods for aluminium, beryllium, potassium, and zinc. A method for the separation and identification of molybdenum and tungsten was also described by Blackman. In all three papers an electrographic method of sampling was suggested.

Mr. Nall made some comments on details of the apparatus. The best shape for the head of the electrode was conical, and a graphite counter-electrode was superior to aluminium, which could be corroded by acid electrolytes. Mechanical properties were an important factor affecting the choice of a filter paper. The three desirable properties for a filter paper to be used in this apparatus were:

(i) An even wetting rate in all directions (the ' directional effect ' was marked with some papers)
(ii) A high enough wet strength
(iii) A sufficiently large absorption to allow the washing operation to be carried out in a reasonable time.

Although the method was still in its infancy, it had many advantages. It gave accurate results and could be used in the field; small amounts of metals could easily be handled semi-quantitatively; and the apparatus was simple. He thought that the method would find many applications in the future.

Discussion

Replying to questions, Mr. Nall said that he was confident that copper, cobalt, and titanium could be determined if the need arose. With practice, the four elements manganese, nickel, chromium, and molybdenum could be determined in less than half an hour. A small grinding wheel was used to remove scale and rust and give a flat surface. The tests would not work if rust, grease, or scale were present. A cleaned area of above 1 in^2 was all that was required.

Small irregularities in the surface did not affect the results; the soft wet filter paper accommodated itself to any roughness. No appreciable absorption of the electrolyte by the graphite could be detected. The reproducibility was better for nickel than for manganese. Temperature had a negligible effect.

Safety in the Laboratory

The final paper in this session was presented by Dr. **L. J. Burrage** of the General Chemical Division of Imperial Chemical Industries Ltd., who spoke on safety in the chemical laboratory.

The chief troubles in a laboratory lay in lack of knowledge, lack of experience, or a somewhat blasé attitude on the part of the experienced. He had been regarded on many occasions as being unduly fussy and had been told by experienced men who were carrying out risky operations in an unsafe manner, " Don't worry, I have done this hundreds of times." If the operation were dangerous there would some time be an accident, and no one knew when it would occur. The senior man must become an ardent disciple of safety for two reasons: he had a moral obligation, to his juniors particularly, to see that they came to no harm, and an obligation to his company to keep his staff fit and working.

How could this background of safety be instilled ?

How could people be interested in this subject, and how could an awareness be created ? The first essential was to ensure a friendly attitude and establish a family spirit throughout the department concerned. This was not, of course, the peculiar prerogative of safety; it was fundamental to the good running of any department, but it was absolutely essential for safety. Without this bond the correct safety instructions and equipment could be issued, but the senior man was then concerned with ways and means of making his staff carry them out.

The senior man must take a personal interest in his staff and show an obvious interest in their welfare; he stressed the word *obvious*. Too often one heard that the management was not interested. What was wrong was usually that there was no obvious interest. It was the human touch that mattered and that was appreciated. It should always be remembered that the management was not some remote, nebulous body composed of senior men. The immediate management was anyone who had even one person working under him. Once staff realized that the senior man was sincerely interested in them as individuals, they in their turn became prepared to interest themselves in the things in which the senior man was interested. If each person concerned were studied and the best method of approach chosen, outstanding success could be achieved.

Every individual must be made aware of the risk but never frightened. He must be provided with the best equipment for his protection and he must know that it would always be in first-class order. When choosing equipment, other things should be considered as well as efficiency: equipment should be as comfortable as possible to wear and should make the person look as reasonable as possible. Both these factors helped in encouraging people to wear it. He had tried on many goggles and masks that were so uncomfortable to wear that he would not attempt to coerce his staff into using them. The less conspicuous the equipment, the better it would be liked and the more it would be used.

Analysed into its fundamental constituents, safe working was in almost all cases composed of a large number of obvious do's and don'ts, most of them very simple.

If there were any serious risk of splashing and burning the face, a face shield should always be worn; there were several very comfortable types available. If the circumstance did not warrant this but there was any risk at all to the eyes, goggles must be worn if there were a vapour hazard; otherwise safety glasses would suffice. A new French glass, lighter and stronger, was now becoming available. Safety instructions should use the word *must*, not *should*. *Should* allowed latitude, but there could be no latitude in safety matters.

If there were a dust hazard, the work must be carried out in a fume cupboard or dry-box and the assistant equipped with a mask capable of stopping the finest particles.

It should always be remembered that protection of the equipment at source was the first line of defence and must always be so; personal protection was the second and last line. For example, metal screens should be provided for Buchner flasks.

The standard of housekeeping was also important. There should be a place for everything and everything should be in the right place. Winchesters should never be stored above head height so that there was a risk of the contents being spilled over the person. This risk could be avoided, but unfortunately some people thought it unnecessary to take these precautions. The excuse often made was that conditions were congested; in these circumstances it was even more necessary to be extremely meticulous over tidiness.

Gas cylinders lying on the floor constituted a serious tripping hazard. They should be in stands, but with some cylinder stands the cylinder itself had to be lifted about a foot and then dropped in a collar, with a risk of strain to the operator. Others had triangular supports; the hazard of tripping over the cylinder was removed but another was introduced—that of tripping over the supports of the stand itself. It was useless to cure one hazard and substitute another.

Winchesters should never be carried in the hands or under the arm; they must always be in a suitable light container of expanded metal or P.V.C. Wooden carriers were heavy and cumbersome and tended to cause trouble because of this.

He urged that all accidents should be reported to the ambulance room, however trivial the circumstance. By reporting even the most minor scratches, the risk of sepsis was almost entirely eliminated.

At his own establishment, which had a staff of 650, the number of casualties reported every month to the Ambulance Room was from 170 to 190 six years ago, when minor accidents were not reported. In 1955, the average was less than 22 a month, and this figure included all the minor accidents, some of them quite trivial.

He urged all members of the conference to learn first-aid. In his department there was at least one person qualified in first-aid in every laboratory, so that in the event of an accident treatment began immediately. This was extremely valuable, particularly for shock. He strongly recommended installing first-aid cabinets at various points throughout the entire research department.

Dr. Burrage drew attention to two other sets of fixed equipment which were strategically placed throughout the department. First, showers should be provided to deal with a gross spillage of corrosive material over a person. Because the accepted overhead type was relatively useless for dealing effectively with a leg or the lower part of the body, a shower was designed that could be used directly on any part of the body. It had proved to be very effective. The second item of fixed equipment was the compressed-air mask working off a separate compressed-air main. It had been shown to have so many obvious advantages that almost all Puretha masks had been withdrawn from service.

Other fixed general service equipment for every laboratory included eyewash bottle cabinets, face-shield cabinets, and glove racks. Although still issued to individuals, gloves could be seen or inspected at any time when kept on racks. Guards and safety equipment were painted orchard green. This safety colour of green had proved a valuable plank in preaching safety, for it was present through the entire twenty-four hours, day by day, and month by month.

Fire extinguishers should be in obvious positions and painted bright red. They should be grouped in panels and kept clear of other equipment, and hung, not at the danger point, but near it; otherwise, if a fire occurred it might be impossible to reach the extinguisher. The main equipment should be at the door of each laboratory so that a man could advance to the attack with the way of retreat open behind him. Others coming in to help could then pick up equipment as they entered. Fire alarms and fire blankets should also be included in these panels where necessary.

Dr. Burrage showed lantern slides to illustrate the points he had made in his talk.

Discussion

In reply to a question on hazards arising from the use of mercury, Dr. Burrage said that in the laboratory the

chief risk was not from mercury seals, which presented only a small surface area, but from spilt mercury. He recommended that bottles of mercury should not be stored on trays, as this practice tended to cause mercury to be spilt. A contributor offered the hint that lead foil was useful for picking up small globules of mercury.

On hydrofluoric acid burns, Dr. Burrage said that an injection of calcium glucinate (by a doctor) after washing the burn and rubbing in magnesia paste relieved the intense pain immediately. He agreed with another speaker who said that hydrofluoric acid could be replaced by potassium fluoride for nearly all purposes except dissolving silica.

Asked about the marking and colouring of gas cylinders, he replied that this was a vexed question. So many different ones were now used that it was very difficult to remember which was which. Some suppliers added to the confusion by refilling cylinders without repainting them, with the result that the colour identification was rapidly lost in rust. He would rather paint all cylinders aluminium and add the name of the gas in bold letters. For gas cocks a simple two-colour code was enough: red for inflammable gases, yellow for toxic ones.

THIRD SESSION: CORROSION

In the last session of this conference, Dr. **U. R. Evans** F.R.S., of the University of Cambridge, spoke on quantitative research on metallic corrosion.

There were, he said, two possible aims in the quantitative study of corrosion reactions. The first was the accumulation of useful facts to combat corrosion. The second aim was to understand the mechanism of corrosion reactions; this would provide only a limited amount of information of immediate practical value and would appeal more to the 'pure scientist.' Others might prefer to apply themselves to reducing the vast waste that today results from corrosion; even a small reduction would be a great contribution to economic problems.

At first sight, 'facts without causes' might be advocated by the 'practical man'; but in corrosion there were too many independent variables (e.g. water supply, velocity, atmosphere, composition of the metal), and to test all possible combinations would be impracticable. On the other hand, even a little knowledge of the mechanism of corrosion would enable a reasonable surmise to be made about the probable result of a given combination of circumstances. Both types of research were therefore required, and both had been carried out at Cambridge.

In this lecture he had decided to concentrate more on the 'pure science' aspects of the subject, with special reference to the attempts that had been made at Cambridge to verify that wet corrosion processes were caused by currents flowing between anodic and cathodic areas. Measurements had shown that there was good agreement between current and corrosion rate (measured by loss in weight). The mechanism of corrosion had thus been put on a quantitative basis.

Two main types of chemical wastage were encountered: the first was characterized by the formation of films, especially oxide films, which began to form quickly at first and then slowed down unless the oxide were removed. This type of corrosion was not of practical importance at ordinary temperatures, certainly not for iron in dry air. The second type of corrosion was exemplified by the reaction which took place when a metal was partly immersed in, say, a salt solution. Under these conditions what could be described as 'a sort of oxidation' took place, but no protective film was formed. Thus, with zinc, the following reactions took place:

$$O + H_2O + 2e = 2OH^- \quad \text{(cathode)}$$
$$Zn = Zn^{2+} + 2e \quad \text{(anode)}$$

These two reactions could only take place simultaneously. Any film formed was roughly perpendicular, not parallel to the surface, and gave no protection to it. Corrosion could therefore go on indefinitely.

These facts were known qualitatively as long ago as 1923. The first quantitative study was made by Hoar at Cambridge with pure iron and specially prepared steel in the thirties. He studied the mechanism of corrosion quantitatively by measuring the current and comparing it with the corrosion loss. This could not have been done without the production of the special steel by Dr. Hadfield, Chairman of the Iron and Steel Corrosion Committee. The steel was very uniform and the corrosion pattern of specimens immersed in potassium chloride was always the same.

This pattern, in which corrosion was confined to the outer edges of the specimen, was therefore called the 'ideal distribution.' (Samples containing impurities usually corroded at points on the face as well as at the edges.)

Hoar was thus able to take specimens, cut them along the boundary between the corroding and non-corroding areas, and mount the two segments on a glass plate so that they were just out of contact. He joined the two parts to a meter after having protected the cut edges with wax. He was able by this means to show that the current passing was equivalent to the corrosion rate in the sense of Faraday's law. This method was only applicable to concentrated solutions, and if by chance there were even one point of anodic attack on the so-called cathodic segment, the experiment would be invalidated.

Hoar therefore developed another method. He cut and mounted specimens as before and joined them to an external source of current. For each current value, the potential drop at the cathode was measured at a point just below the water-line by means of a tube leading to a calomel electrode. Having thus obtained a relation between potential and applied current, it was possible for Hoar to apply the method to undivided specimens, and thus obtain the corrosion rates simply by measuring the potential. Very good agreement was obtained between the observed and calculated values of the corrosion rates. No arbitrary value had been used in the calculations. Had the mechanism of corrosion not been electrochemical there was no reason to expect the two sets of figures to be even of the same order of magnitude.

Iron was the first metal studied quantitatively in this way. Some years later zinc was studied by Agar, who investigated the distribution of potential throughout the liquid in which a specimen was immersed and applied Ohm's law. Equi-potential lines were plotted and the current was calculated from them; the agreement between the observed and calculated values was within a few per cent. This work was interrupted by the war.

Corrosion went on continually when the anodic and cathodic products were soluble. If they were not, the process might stifle itself, as happened when iron was immersed in concentrated sodium phosphate solution. If the phosphate solution were less concentrated, corrosion would occur. A similar effect was produced with sodium carbonate. These results could be explained in terms of the formation of thin films of gamma ferric oxide in the concentrated solutions.

At the 'borderline' concentrations, Mears, also at Cambridge, found that the behaviour of iron specimens in sodium carbonate depended largely on their past history. Later, the lecturer had used a dielectrode composed of two oxidized copper electrodes surrounded by wet filter paper, and insulated from each other. The electrodes were connected to a milliammeter. A fresh scratch on the surface of the specimen increased the

probability of corrosion taking place, and it was possible to show that a current passed between the anodic area on the scratch line and the cathodic area around it.

Thornhill subsequently constructed an apparatus that could be calibrated against known currents from an external source. The experimental technique was difficult, but he was able to measure the currents and compare them with the corrosion rates. Surprisingly, the current was found to be higher than was expected. This was explained by stagnant conditions in the filter paper; ferrous ions remained close to the metal surface after they had been formed and conversion to ferric ions took place, giving additional current.

Yet another type of corrosion had been studied by Nordhof. In his experiments a specially constructed dielectrode was used to study the potential gradients round fully immersed specimens. Here again the observed and calculated values were found to agree within a few percent.

It was fortunate that polarization occurred, or iron would corrode very rapidly. As the concentration increased, the intercept between anodic and cathodic polarization curves was reduced, until the potentials of the cathodic and anodic areas became equal.

Hoar prepared corrosion/time curves and showed that the corrosion rate was constant. He then plotted corrosion in a given time against concentration. The graphs showed that the limited solubility of oxygen in the liquid at higher concentrations reduced the rate of corrosion. At these higher concentrations, the corrosion rate was proportional to the solubility of oxygen in the liquid concerned.

Discussion

Dr. Evans was asked whether any information was available on the action of organic compounds such as ethylene glycol on corrosion rates. It was known that ethylene glycol reduced the solubility of oxygen. He replied that organic compounds acted in different ways. Some could be quite corrosive. The difficulties encountered with ethylene glycol had been overcome fairly well by work carried out by the Chemical Research Laboratory and by industry.

Oxygen solubility might not be the most important factor. On steel there were large anodic and cathodic areas several millimetres or even centimetres apart. On cast iron, anodic and cathodic products were close together and a protective layer might be formed. Under some conditions of geometry and mechanical treatment cast iron would serve where steel would not.

Replying to a question on the comparative corrosion resistance of wrought iron and steel, Dr. Evans said that the corrosion of wrought iron was a complicated matter. The metal contained alternating layers, some more resistant (*R* zones), others quickly corroding (*Q* zones). All these zones were usually more or less parallel to the surface. If, however, the zones ran, as they sometimes did, at a small angle to the surface, the *Q* zones would be attacked where they emerged. These facts explained why there had been so much contention about the corrosion resistance of wrought iron. It was a pity that the geometry of the matter had not been better recognized by those who used wrought iron. If it had, the results could have been obtained on all occasions, and not just on some.

The layered structure of wrought iron had been known for some time. The *R* zones were layers in which the sulphur was enclosed in a geometrically inaccessible form and could not easily be reached by the liquid. Chilton had discovered zones of a third type, which he called *V* (very resistant) zones. *V* zones occurred only in piled wrought iron and were relatively rich in noble impurities (copper and nickel) which accumulated in them to form thin layers of what was practically an alloy steel at the interfaces between the plates in the pile. *V* zones were probably not present in the older forms of wrought iron; less alloying material would have been introduced with the scrap in earlier times.

In the atmosphere, if insufficient protection were given to the edges of wrought iron, corrosion would take place along the *Q* zones and the consequent expansion (owing to the larger volume of the corrosion products) might cause the bars to swell and split. This was often seen in coastal regions. The importance of the geometrical factor was shown where a bar in perfect condition was found adjacent to another that had disintegrated.

In answer to a further question on the relation between sulphur and corrosion resistance of steel, Dr. Evans said that sulphur greatly increased the attack upon the metal in acids and in acid atmospheres. Hoar and his co-workers had studied this problem as it concerned tinplate and food packs in contact with nitric acid. They found that there was a tendency towards an increase in corrosion rate with increasing sulphur content, but they also found that the relation between sulphur and copper was more important. The presence of hydrogen sulphide lessened the polarization at the anodes, but copper could precipitate it as copper sulphide. Steels for which the ratio of copper to sulphur was more than a certain critical value were much more resistant than others with a lower ratio of copper to sulphur. In a general way these principles might also be applicable to steels in acid atmospheres.

A contributor to the discussion suggested the possibility of graphitization of cast iron being caused by dilute solutions of sulphuric or sulphurous acids. Commenting on this, Dr. Evans said that the effect of these acids would be to set up local cells; a solid corrosion product that would protect the metal or slow down its corrosion would not be left. Ultimately, with many forms of cast iron, the action did slow down somewhat. In the early stages, however, the attack of cast iron in acid increased with time. Later, the attack on the cast iron slowed down, but that on the steel did not. Bacterial action also entered into many types of graphitization.

There was some discussion as to whether theories for corrosion in aqueous solution could be applied to fused salts. One contributor expressed the opinion that current could flow in fused salts, although the phenomenon was as yet imperfectly understood. Dr. Evans pointed out that many factors would have to be considered.

There was also some discussion on the effect of the copper/sulphur ratio on the polarization of nickel anodes in plating vats and of the effect of nickel oxide on the rates of polarization and depolarization. Dr. Evans suggested that the physical state of the second phase might be very important; it might prevent the formation of a protective anodic film. Another speaker said that the mechanism was complex and that the balance between copper in and out of solution was very critical; some copper dissolved in the anode, some made its way to grain boundaries. If the balance were correct, the desired effect was obtained.

In answer to a question on the mechanism of stress corrosion, Dr. Evans explained that much depended on the heat-treatment and rolling of the specimen. Corrosion might begin at grain boundaries and then, on reaching a susceptible layer, turn horizontally. Laboratory tests might be deceptive where such layers were present. Thus, specimens that had a long life in a laboratory corrosion test in which they were under straight tension had been known to fall to pieces as soon as torsion was applied to them.

Positioning of Machine Dials Decided by Human Eye Observation

By Richard B. Body, M.R.C.S., L.R.C.P., D.I.H.

SYNOPSIS

The problems of optimum size and location of the draught indicator dial in a modern slabbing mill are examined. Optical measurements made on hypothetical operators showed that the normal human eye is adaptable to considerable variations of light and accommodation.

1401

INTRODUCTION

AS A RESULT of a decision to increase the tonnage potential of The Steel Company of Wales Ltd. by about one-third, extensive developments will be undertaken during the next two to three years. An important item will be the virtual rebuilding of the present slabbing (or blooming) mill.

The principal dial of such a mill is the draught indicator, for giving readings of the variable distances between the rolls of the mill as the steel ingot is transformed to the slab. One question requiring a decision was the position that this dial should occupy on the new mill. The two possible alternatives were:

(1) To have a dial, suitably modified, located on the mill housing, about 42½ ft away from the operator, or

(2) To maintain the dial in its present position relatively near to the operator in the control cabin or pulpit itself. The dial for the present mill in the cabin is 2 ft in diameter, approximately 4 ft from the operator's eye whilst he is comfortably seated for rolling (Fig. 1).

Arguments submitted in favour of the first alternative were:

(*a*) That both installation and mechanical maintenance would be easier with the dial on the mill

(*b*) It appeared theoretically to be an advantage to have a dial in the area to which the operator normally had to direct his attention whilst watching the actual rolling process.

The alternative site, with the dial relatively near to the rollerman, appeared to necessitate frequent changes of focus of the eye, when attention was directed from the mill rolls to the dial and back again, the true effect of which was unknown.

As these alternative sites were clearly controversial, the problem was referred for medical consideration and investigation.

At the outset it had to be stressed that, in spite of efforts to determine methods of measuring eye fatigue, especially for aircraft pilots, no means was yet available. There could therefore be no direct method for calculating the effect which dials in either of the two alternative positions might produce operationally.

Practical measurements were, however, made on the site, using pupil changes of the human eye as a means to determine the amount of accommodation required Tests were conducted with and without the existing mill in operation, and using medical staff who had clinically normal vision as subjects for measurement.

PUPIL DISTANCES

The mean distance between pupils of the subjects chosen, when acting as hypothetical operators and looking at the existing dial within the pulpit, was 63 mm. The mean distance between the pupils with the operator looking at the mill housing, or at the possible alternative site for the dial, was 65 mm, a differential of only 2 mm. The mean full range of pupil change for the persons tested, when accommodating from distant vision (infinity) to near vision (reading) was approximately 15 mm.

The reason for the very small change which was noted in this instance was undoubtedly due to the fact that the present dial was not abnormally near to the eye; actually it was about 4 ft distant. Also, because the dial was large, it did not require close scrutiny for the pointer to be seen easily, and the requirement for change of accommodation was obviously very small indeed.

PUPIL DIAMETERS

With the 'operators' looking at the dial when located in the pulpit about 4 ft from their eyes, the mean pupil diameter was 4 mm. With the 'operators' looking at the mill housing, at the possible alternative dial position some 42½ ft from the eye, the mean pupil diameter was 4·5 mm, a difference of 0·5 mm. The mean range of pupil diameters for the subjects tested was between 2 mm, when fully contracted for bright light, to an average diameter of 7 mm when dilated for dull light, a total range of 5 mm. Similarly, the full range of pupil diameter for accommodation from

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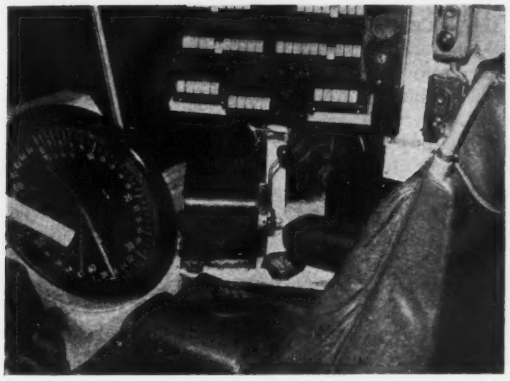

Fig. 1—Present position of dial

very near vision to far (infinity) vision was also found to be about 5 mm.

The change of pupil diameter of only 0·5 mm is but a small percentage of the full range possible, yet this was all that was necessary when operating with a dial in the pulpit. This would account for the popularity of the present system with the operators themselves.

DIAL SIZE RELATED TO OPERATIONAL DISTANCE

The distance from the operator's eye, when sitting well back, to the centre of the dial in its original position, in the pulpit, varied between 57 in. for a man 5 ft 2 in. tall, to 59½ in. for a man 6 ft tall. Therefore the size of the operator need not alter calculations to any great degree, and the mean distance was approximately 58 in. In practice, however, it was found that all operators inclined slightly forward, and in doing so lessened still further the small difference between distances obtained for individuals of different heights.

The distance of the eye, in the working position, to the present dial was about 4 ft. The diameter of the original draught indicator dial in the pulpit was 24 in. The angle subtended by the original dial to the eye of an operator occupying the average position at the controls was 28°.

Fig. 3—Mill housing, showing alternative site for dial

The distance of the operator's eye, when seated, to the centre of the mill was 47 ft 6 in. or 42 ft 6 in. from the mill housing, the possible alternative site for the new dial (Fig. 2). At this alternative site, in order to subtend an angle at the eye equal to that subtended by the present indicator dial and not lose in clarity of perception in doing so, all other factors being equal, the new dial would have to extend from the roll table to the first motion shaft of the screw drive on the head of the housing, a height of 22 ft 3 in. (Fig. 3). Therefore a dial placed in the alternative position on the housing would have to be 22 ft 3 in. in diameter; this is obviously an impossible size, but with any smaller diameter, there must inevitably

Fig. 2—Relative positions of pulpit, mill rolls, and housing

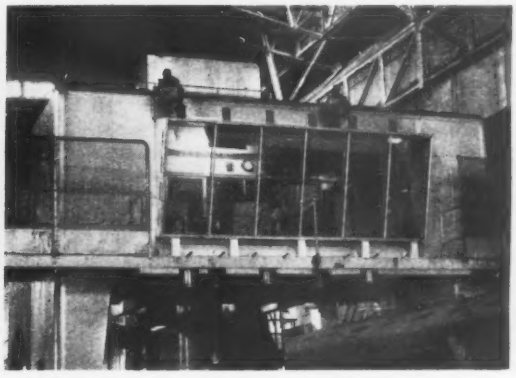

Fig. 4—Mill pulpit

be a loss of clarity with a consequent increase in eye strain.

LIGHT VALUES

The illumination of the original dial was by a circle of fluorescent lighting tube, 2 ft in diameter located under the rim of the dial. Such an arrangement prevents the tube itself from being seen when viewed directly from the front. The light value of the existing dial (with the pulpit lights turned off) was found to be equivalent to 10 foot-candles. The radius of the existing dial was not large enough to result in any measurable decrease in light value at the centre of the dial, compared with that of the periphery.

Measurements of the light intensity of the mill building itself, tested from the pulpit steps (Fig. 2) and the platform in front (Fig. 4), gave readings of 2 foot-candles.

The intensity of light measured inside the pulpit, and right against the double thickness of toughened protective glass (which was well cleaned at the time readings were taken) was found to be 0·98 foot-candles, i.e. a reduction when passing through this glass screen to almost exactly half its original value. Any dial located outside the pulpit would therefore need to have its calculated necessary light intensity approximately doubled to compensate for this extra requirement of passage through the protecting screens.

If a dial of the present size were to be removed to the mill housing, it would occupy a new position, not 4–5 ft but 42¼ ft from the seated operator. If it were not enlarged in any way, then clearly at this new distance the image, which would be seen by the operator, would be so small that it would appear, for all practical purposes, as a unit source of light. Under these supposed circumstances the inverse square law would apply for the calculated required light value for the dial in this new position.

With the dial on the mill proper, the new operator-to-dial distance would be some 8·5 times as great, and the new light requirement would be $8 \cdot 5^2$ or about 72 times as great. A theoretical level, however, which would again have to be doubled to 144 times, to compensate for the passage of the image through the screens, would give an ultimate level of about 1440 foot-candles, a level at which glare could obviously be anticipated. This calculation assumes there had been no change in dial diameter, and that no optical devices or telescopes had been used.

If the dial, in addition to being removed to the mill, were also to be enlarged, as previously suggested, to about 22·25 ft to present a comparable image on the retina, then since it would no longer appear as a unit source of light, the inverse square law could no longer be applied. If peripheral lighting was again used, the centre of the dial would be some 11 ft from the light source, compared with a distance of only 1 ft, which is the radius of the existing dial.

To avoid the dial centre appearing relatively dark, the lighting would require to be increased by a similar proportion (or by 22 times allowing for the passage of light through the screen) to a new level of 220 foot-candles; again, glare could be anticipated compared with a general light level of about 2 foot-candles for the rest of the mill area.

A system of floodlighting from the region of the pulpit roof on to the dial would be hazardous, owing to the risk of reflection from the dial face. There would also be the risk of the blinding effect which might result from using spot lights anywhere in the area to workers who might be in contact with moving machinery elsewhere on the mill floor. Existing lights (Fig. 4) focus on to the rolls, not the housing.

Lighting by uniform translucence behind and through the dial face would still mean that the previous lighting level would need to be doubled to 20 foot-candles, to compensate for the passage of light through the pulpit glass screen. This low order of increase would only be possible if the dial face were fully enlarged to the theoretical requirement of 22 ft 3 in. in diameter. Any smaller enlargement would necessitate a further increase in light requirement.

It should be understood that no allowance whatsoever has been made for the unknown quantity of dust and fume arising from the mill itself, nor for the inevitable accumulation of dirt on the dial face which, if located on the mill housing, could only be wiped clean at relatively infrequent intervals. Near the operator, however, the dial is in a relatively clean atmosphere, but should it become dirty or cloudy it is readily accessible for immediate cleaning.

If it were located on the mill, a compromise would obviously have to be reached between dial size, the use of optical equipment, and light requirement, but it would be extremely difficult to obviate glare whichever course was adopted. Glare is, however, entirely absent with a dial placed in a pulpit reasonably near to the operator.

OBSERVATION

The peculiarity about this particular investigation is the distance involved between the potential positions for the placing of a single dial. This allows a coarse means of measurement to be utilized, which would have been quite impracticable had the alternatives been measured in a few inches instead of many feet.

CONCLUSION

Because the original draught indicator dial was reasonably distant (about 5 ft) from the operator, no great strain needed to be put upon him for interpretation of the readings thereon. Theoretically, the placing of a dial as near as possible to the actual work being done seemed advantageous. Measurements of the observing eye itself proved, however, that accurate focusing was neither necessary nor practised, and consequently fatigue was subconsciously minimized.

These tests showed that pupil changes which were required for both accommodation and for light variations were, in practice, relatively very small, compared with the full ranges which are possible for the normal eye.

Acknowledgments

The author wishes to thank Mr. W. F. Cartwright, Assistant Managing Director of the Steel Company of Wales Ltd., for his encouragement and permission to publish these results, and also members of the engineering and production staffs at Margam, and Dr. W. Cochrane of St. Thomas's Hospital, London, for their advice and assistance.

A Century of Cowper Stoves

By Daniel Petit

SYNOPSIS

The paper begins with a brief account of the life and work of Edward Alfred Cowper (1819–1893), inventor of the hot-blast stove. This is followed by a critical survey of modern plant and practice, with a comparison between Continental and U.S. installations. The paper ends with an outline of possible future developments, covering large-capacity, very high-temperature, and high-pressure stoves. 1387

THE FUNDAMENTAL PATENT on which the construction of all Cowper stoves is still based dates from 19th May, 1857, a hundred years ago.

The Victorian era produced many great inventors in England, especially in the field of iron and steel-making. Edward Alfred Cowper must be one of the least well known of these, yet his invention is one of the most important in this field. Every blast-furnace in the world is equipped with two or three stoves in which some 30,000,000 calories per hour are consumed. Calculating the amount of heat this represents gives some indication of the role that improvement in these stoves can play in world economy.

The century of Cowper's invention is a fitting occasion to pay him the tribute that he deserves. The best way of honouring him would seem to be to write a book describing his life and work, in which an attempt should also be made to assess the present state of the technique he invented and the further progress which can be made in his invention. This book is to be published shortly; it will be a work of collaboration, written by engineers recognized throughout the world as experts in what might be called "this well-behaved child of ironmaking"—in fact, so well-behaved that until now it has received too little attention from engineers.

Having spent thirty years studying the problems of construction and utilization of Cowper stoves, the present author was well equipped to assemble the documents needed for such a work.*

In order to remain absolutely impartial, proper names have been avoided, and personal opinions have only been given where it seemed evident that a particular solution had advantages. However, this paper will very likely provoke criticism or discussion; in France it is said that "discussion enlightens" (*de la discussion jaillit la lumière*), and our object will be fulfilled if these discussions are of benefit to those concerned with these matters.

THE LIFE AND WORK OF EDWARD ALFRED COWPER

Edward Alfred Cowper was born on 10th December, 1819, the son of Edward Cowper, Professor of Engineering at King's College, London. Edward Cowper senior has already shown that he had an inventive mind, notably by his improvements to the design of printing presses.

Little is known about his son's childhood. It is known that when he was 14, he was taken into J. Braithwaite's engineering offices. He was still an apprentice when in 1841, at the age of 22, he invented a detonating alarm signal for stopping trains in the event of fog.

In 1848, he joined Messrs. Fox and Henderson at Birmingham, where one of the projects on which he was engaged was the design of the entrance hall of the railway station; its span of 211 ft made this the largest structure of its kind at the time.

He resigned from Fox and Henderson in 1851 to set up his own office in London as a consulting engineer. It was in 1857 that he invented what became known as the 'Cowper Stove' and he devoted himself to its further development until the end of his life. During that time he built for the Royal Navy an improved steam-engine, and, in his spare time, he verified Joule's Law.

Cowper died on 9th June, 1893, aged 73, highly respected, and leaving his business to his son Charles, whom he had made a partner.

In order to understand the part played by Cowper in the development of the stoves which bear his name, it is proposed to summarize the salient points of three documents:

The patent of 1857
The paper given to the Institution of Mechanical Engineers in 1860
The paper given to The Iron and Steel Institute in 1883.

The 1857 Patent

Patent No. 1404 of 19th May, 1857 (*see* Fig. 1) sets a fine example of modesty to all engineers who, since Cowper, have been concerned with Cowper stoves.

In it are to be found most of the fundamental ideas which, for the last hundred years, have been used in various forms by successive generations of engineers. For example, having set out the fundamental principles governing reversal of gases, Cowper proposed, as early as the second page, the use of crooked flues to encourage heat exchange.

Further on he suggested that perforated refractory plates should be used. He stressed the advantages of

* The author would like to express his grateful thanks to Mr. A. E. Chattin, Assistant Secretary and Librarian of The Iron and Steel Institute, and his staff, who have kindly helped him in the preparation of this paper, which is really a summary of the book.

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Monsieur Petit is President of the Société de Technique Industrielle, Paris.

a high blast temperature and he proposed to accelerate combustion by using a fan.

He even went so far as to suggest the use of metal checkers to increase the efficiency; this idea, as far as the author is aware, has still not been applied; it will perhaps be necessary to wait some years more for some new 'inventor' to adopt it.

Paper to the Institution of Mechanical Engineers, 1860

In this paper, which is more complete than his patent, Cowper emphasizes the advantages of his invention and gives details of its methods of application.

He proposes reversal every 2 h and the use of water-cooled valves for the hot blast, and states that the waste-gas temperature can be lowered to 150–200° F. He quotes the case of two gas-fired stoves installed in a works in England, capable of heating 1000 ft^3/min of blast to a temperature of 1200–1400° F.

In replying to the discussion on his paper, Cowper stated that he received a royalty of 6*d*. per ton of finished steel for the use of his stoves.

Paper to The Iron and Steel Institute, 1883

By the time this paper was given, Cowper's invention was 26 years old, and there were already 360 stoves in operation all over the world. As a result of the experience gained in their operation, the inventor was able to recommend the use of 1½-in. flues and to advocate the construction of circular stoves; he also advocated the use of burners operating with only 13% excess air.

To understand Cowper's inventive genius better, it is as well to remember the state of engineering in his day. The only means of measuring high temperatures was by reference to the melting point of lead or antimony, for example; only towards the end of his life did Cowper become acquainted with the calorimetric pyrometer, which he considered to be a great step forward.

Cowper showed himself to be unquestionably an inventor of genius. He also displayed a quality which is very English: he applied himself to his invention and its perfection so as to turn it to the best possible account. It is in no sense derogatory to add that he also seems to have shown considerable business acumen.

There would be no object in discussing in this paper the successive improvements in Cowper stoves since 1890, since any metallurgy course gives them. It will therefore be devoted to a study of the present state of Cowper stoves and the improvements which could be made in the next few years.

COWPER STOVES OF TO-DAY

Owing to limitations of space, only a short summary can be given of the principal arrangements at present adopted in the construction of Cowper stoves, omitting the description of apparatus, which might have been of some interest.

Every Cowper stove consists of a large cylindrical shell, containing a vertical combustion chamber and a checker-filled zone in which heating gas and blast are circulated alternately. These stoves are all of about the same size, about 7–8 m in diameter and 30–35 m high. All modern stoves have reasonably high efficiencies (some exceptions will be mentioned later).

Table I

MAIN CHARACTERISTICS OF TWO U.S. AND TWO CONTINENTAL STOVE CHECKERWORKS

8-m stove with conical shell
Dia. of combustion chamber 2·2 m
Horizontal surface area of checkers 30·4 m^2
Height of checkers 26 m
Volume of checkers 790·4 m^3

Characteristics	U.S. Checkerwork		Continental Checkerwork	
	No. 1	No. 2	French	German
Av. weight per m^3, kg	1260	1252	1252	1278
Total weight, tonnes	996	990	990	1010
Av. surface area per m^3, m^2	29·8	22·4	39·3	37·3
Total surface area, m^2	25,550	17,500	31,100	29,500
Surface area per tonne of checkerwork, m^2	23·6	17·7	31·4	29·2
Blast temperature, ° C	500–700		700–1000	
Waste-gas temperature, ° C	150–250 (sometimes greater)		70–150	

They are generally in service for 20 to 25 years almost without repair. It is for this reason that Cowper stoves are described by the author as the 'well-behaved child of ironmaking.'

Stoves differ from one another principally in the arrangement of the checkers and so this subject will be dealt with first.

CHECKERS

At the start of my career in the construction of Cowper stoves 30 years ago, one of my friends, to moderate my relatively juvenile enthusiasm, told me that the art of building a Cowper stove consisted of making holes in bricks. In fact, just as there are small cars and Rolls Royces, so there are Cowper stoves which can be recommended to a greater or lesser extent.

Many arrangements of checkers have been suggested; broadly speaking, these fall into three types:

(i) Stoves with continuous flues which are circular, square, or hexagonal
(ii) 'Zoned' stoves, with flues that decrease in size from top to bottom
(ii) Modern stoves.

Owing to their simplicity, stoves with continuous flues have found favour with leading U.S. builders.

Zoned stoves, very popular 20 or 30 years ago, are now obsolete. The main objection to their use is the danger of blocking. Space does not permit an adequate discussion of them in the present paper.

Modern Cowper stoves have a radiant section in the upper part, where heat exchange takes place successively by radiation and convection, and a heat-absorbing mass in the lower part for cooling the heating gases; this result is obtained either by the use of small flues or by creating an artificially increased turbulence, together with a large surface area for heat exchange.

These modern stoves have chiefly been developed

Edward Alfred Cowper (1819–1893)

[To face p. 50

A.D. 1857 . . . . . N° 1404.

Furnaces.

LETTERS PATENT to Edward Alfred Cowper, of Great George Street, Westminster, in the County of Middlesex, for the Invention of "IMPROVEMENTS IN FURNACES FOR HEATING AIR AND OTHER ELASTIC FLUIDS."

Sealed the 7th August 1857, and dated the 19th May 1857.

PROVISIONAL SPECIFICATION left by the said Edward Alfred Cowper at the Office of the Commissioners of Patents, with his Petition, on the 19th May 1857.

I, EDWARD ALFRED COWPER, of Great George Street, Westminster, in the County of Middlesex, do hereby declare the nature of the said Invention for "IMPROVEMENTS IN FURNACES FOR HEATING AIR AND OTHER ELASTIC FLUIDS," to be as follows:—

The mode at present employed for heating the blast for iron furnaces consists in driving the air through iron pipes inclosed in and heated by a furnace. The temperature thus obtainable is restricted on account of the injury which iron pipes sustain when exposed to a fierce fire, and also to pressure. Pipes of fire clay cannot be employed in the ordinary furnaces, as they would leak or crack, and the air would escape. By the present Invention I am enabled advantageously to employ fire clay or fire stone, or similar refractory materials, and I can thus heat the air to a very high temperature. For this purpose the air is heated by means of "regenerators," in which the same passages are employed alternately for the products of combustion and the air; or alternate and separate passages or chambers are used, in which case the

A

[*Price 8d.*]

Fig. 1—Photocopy of page 1 of Cowper's patent of May, 1857

Petit]
To face p. 503]

in Europe, notably in Germany and France. Table I shows the principal characteristics of two U.S. and two Continental checker arrangements, one French and one German, for stoves of normal sizes.

As it stands, Table I calls for the following comments:

(1) On the Continent, rightly or wrongly, great importance is attached to the surface area of Cowper stoves. Again, it will be necessary to distinguish between the useful surface area which is in contact with the gases, and that which is not.
(2) A similar comment may be made with regard to weight. In the lower part especially, if the checkers are too thick, a part of their weight plays no part in the exchange of heat.

Although it may be claimed in general that Continental stoves are more efficient than the continuous-flue type, it should be added that, with the object of offering their customers stoves which theoretically have the greatest weight and surface area, some manufacturers have tended to offer stoves with flues that are too small.

It is easy to increase the surface area and the weight of the checkers by reducing the distances between the flues. This solution can constitute a real danger, however. It will be shown later that most failures of Cowper stoves are caused by an obstruction in the upper part, and this is naturally facilitated by using flues which are too small.

Another danger can arise from the use of certain brick shapes, and especially by using walls which are too thin. In the lower part of the stove, the refractories must resist not only compression, but also shearing forces. It is advisable to maintain adequate strength in them.

To summarize, whatever the type of checker, whether with continuous flues or the modern type, care should be taken in deciding on the size of the flues and the thickness of the walls.

The French and German stoves given as examples fulfil these conditions, as years of operation have proved. It can therefore be said that whenever heat must be saved, checkers of this kind can reasonably be considered; in other words, with the present shortage of energy, the use of stoves of this kind is most likely to be extended. It will be seen later that they also fulfil the requirements for improving Cowper stoves, with respect to their output and temperature. In short, in the author's opinion, they best meet to the needs of modern engineering.

Horizontal Intercommunication, Distribution of Gases, and Pressure Drops

Another important question divides the designers of Cowper stoves: should horizontal intercommunication be provided between flues? This question, which is often very superficially treated, deserves thorough investigation.

The author is strongly in favour of using continuous flues, which encourage the distribution of gases in the checkerwork. This distribution is also favoured by an increase in the pressure drop, to which German engineers, with good reason in the author's opinion, attach great importance. The author's experience leads him to conclude that, even with a circular combustion chamber, a correct distribution can be obtained with continuous flues.

Operating Temperature and Heat Storage

So far as the operation of Cowper stoves is concerned, the temperature of the blast entering the blast-furnace is without doubt the most important factor on which U.S. engineers and their Continental colleagues disagree.

In the U.S.A. for various reasons which are not relevant here, relatively low temperature (600° C on an average) are generally adopted, whereas on the Continent 800° or even 900° C are normal temperatures.

In the forthcoming book on Cowper stoves, this question will be discussed by considering the advantages and drawbacks of each alternative with the help of blast-furnace operators and engineers. The saving in coke to which higher blast temperatures generally lead can be mentioned here.

This question is generally related to that of heat storage, which on its own is worthy of very full treatment. Only a limited study is attempted by means of the following observations.

At present, with normal blast-furnace gas and using normal refractories, the maximum blast temperature which can be considered is about 1000° C, and in practice at many plants it is 800–900° C. Under these conditions, the question of heat storage hardly arises.

In the U.S.A. a simplified form of heat storage is at present practised. For example, the primary air is at 800° C while the temperature in the blast is about 600° C and sometimes lower. This temperature is regulated by admixing cold blast.

True heat storage is something quite different. It consists of using Cowper stoves as 'costless gasholders' (*gazomètres gratuits*), according to a definition by the present author. Every engineer would like to have a large gasholder at his disposal to control the utilization of his blast-furnace gas. In many works, it is in fact possible to store heat in the Cowper stoves representing a considerable quantity of gas.

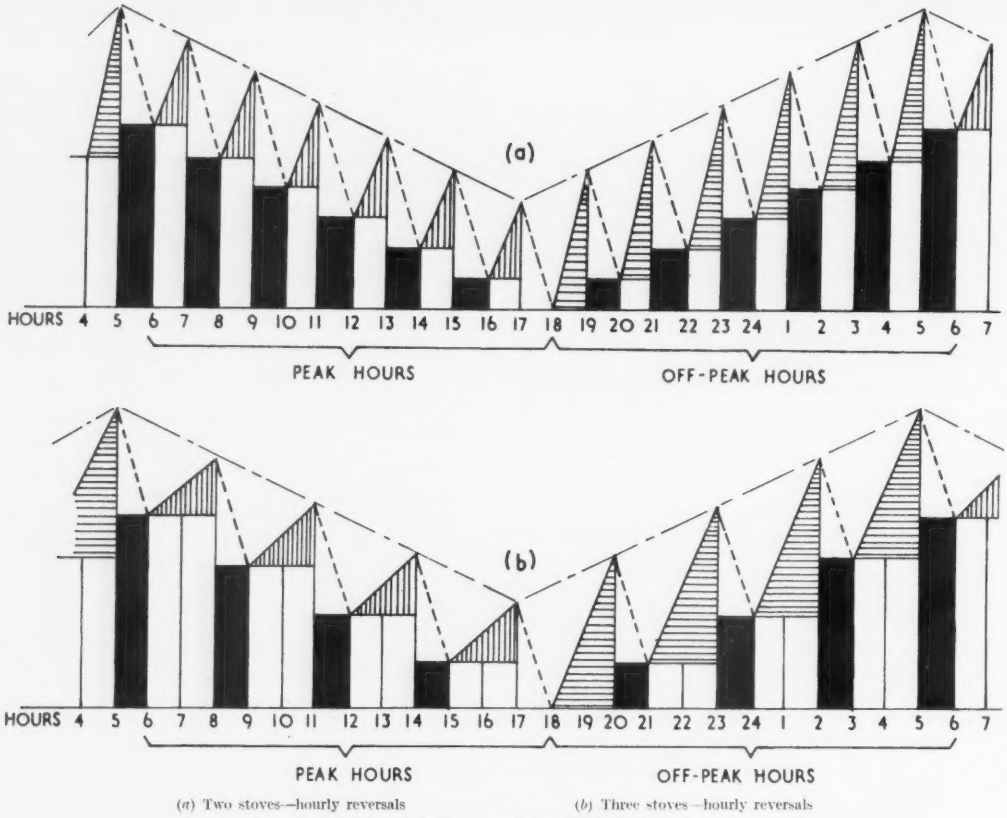
As a typical example, one metallurgical plant feeds a power station which sells its current at very variable cost, according to the hour of the day and the day of the week. By heating its Cowper stoves more during the off-peak hours, this works derives considerable benefit from selling its gas or its electricity during peak hours. Special precautions in construction and in operation are, however, necessary; the checkers must be able to expand freely in the ringwall and it is generally advisable to operate the heat input and discharge as shown in Fig. 2.

Calculations for Cowper Stoves

The calculations for Cowper stoves are a happy hunting ground for the devotees of integral calculus, and some very learned papers have been published on the subject. In practice, however, one often confines oneself to simple formulæ which are empirical or exact to varying extents.

In an attempt to clarify this question, the author obtained the co-operation of a metallurgical company; they agreed to insert several pyrometers in different parts of a stove. Accurate curves have been produced showing the temperature of refractories at different levels and under different loads.

Diagrams prepared from these were published by



(*a*) Two stoves—hourly reversals (*b*) Three stoves—hourly reversals

Fig. 2—Heat storage programmes

the present author in this journal.* Figure 3, which is taken from the earlier paper, shows the possible ' on blast ' times under different conditions.

All our studies of Cowper stoves are based on diagrams of this kind; their advantage lies in the fact that they are based on operating data. Confirmatory tests have established that the results obtained in practice are clearly superior.

The curves in Fig. 3 were plotted for modern highly turbulent checkers, which explains their incurved shape at high temperatures. This is very important, as it shows at the same time the high heat capacity and the low temperature of the waste gases.

With continuous-section stoves, the curves are quite different; they are sensibly straight and much more vertical. For this reason, the waste-gas temperature in U.S. stoves is higher (*see also* Fig. 3).

Construction of Checkers

Checkers in U.S. stoves are generally built in columns: that is, blocks containing several flues are placed one directly upon the other (*see* Fig. 4). On the Continent, many builders have come to adopt the arrangement of interlocking or bonded blocks, each block generally connecting with four other blocks in the upper and lower courses (*see* Fig. 5). This arrangement is especially recommended for stoves that are used for heat storage.

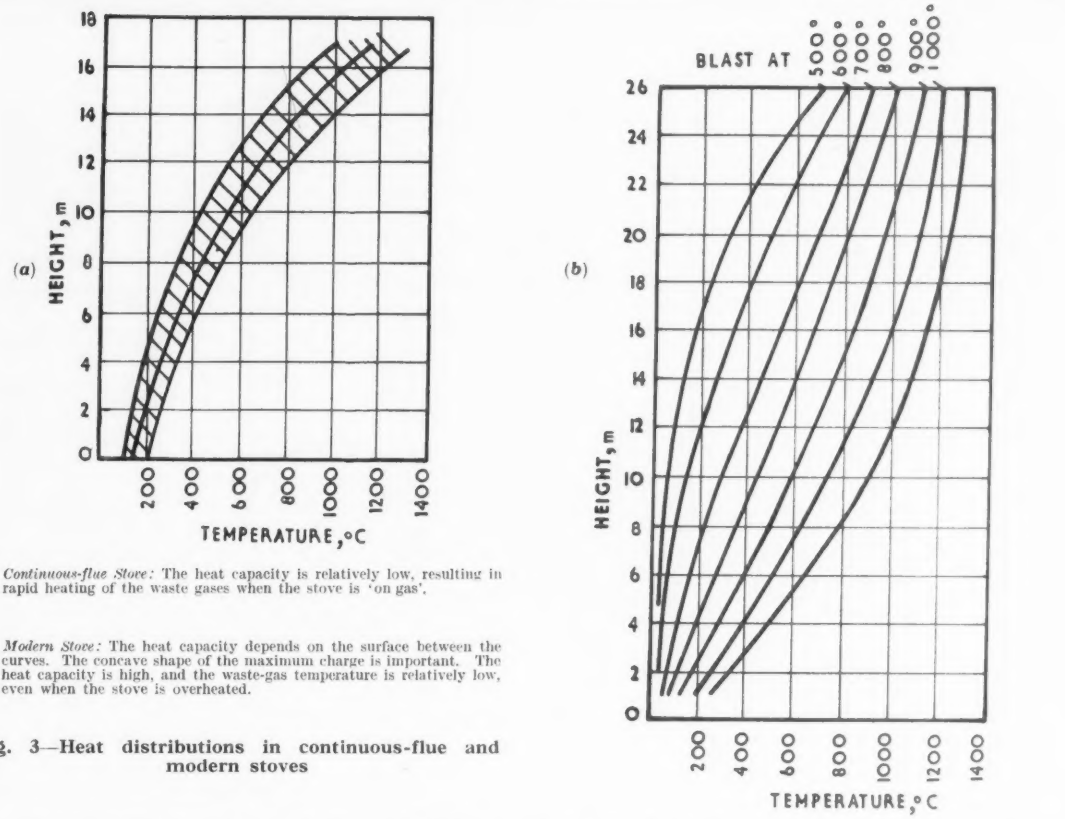
It is evident that in the checker the heat is transmitted much more rapidly than in the stove walls or the combustion chamber, so that, owing to expansion, the upper part of a checker rises and falls relative to the ringwall and the combustion chamber, with an alternating movement which is of low amplitude in the case of hourly reversal, but which can become relatively important where the stove is being used for heat storage.

Furthermore, it is clear that an independent column 200–300 mm wide and 26–28 m high can only remain upright on the periphery if it is in contact at certain points with the ringwall and the combustion chamber. Consequently, there is a reversible sliding movement which is dangerous, especially with circular walls in which the checkers have to be cut to fit on the periphery.

The disadvantage is overcome by using interlocking blocks which enable a stable checker to be made, independent of the ringwall and the combustion chamber. This form of checkerwork requires great uniformity in the thickness of bricks; this can easily be achieved with modern ' dry ' manufacture and careful erection.

A very simple patented device frequently used in Continental stoves consists in mounting the burner on a large elliptical plate, giving an opening of 1·40–

* D. Petit, *J. Iron Steel Inst.*, 1948, vol. 160, pp. 131–138.



(*a*) *Continuous-flue Stove:* The heat capacity is relatively low, resulting in rapid heating of the waste gases when the stove is 'on gas'.

(*b*) *Modern Stove:* The heat capacity depends on the surface between the curves. The concave shape of the maximum charge is important. The heat capacity is high, and the waste-gas temperature is relatively low, even when the stove is overheated.

Fig. 3—Heat distributions in continuous-flue and modern stoves

2 m, for example, through which the materials for construction or maintenance can be introduced easily into the stove (*see* Fig. 5).

Refractories

In the stove checkers, the refractories must be resistant to:

(*a*) In the upper part the chemical action of dust at the temperature of the dome (1150–1300° C in general)
(*b*) For a certain depth of the checkerwork, crushing under load at high temperature (see diagrams in an earlier paper*)
(*c*) In the lower part, crushing or shear
(*d*) Finally, from top to bottom of the checkerwork, changes of temperature.

In practice, most stoves are made with aluminous materials, generally containing 30–42% alumina. Nowadays they are most frequently manufactured 'dry' under conditions which ensure products remarkable for shape and size.

In the U.S.A. it is now considered advanced to use in the hot parts 18–20% alumina bricks, but on the Continent, after widespread use, they have generally been abandoned. This question has already been discussed at length.†

In fact, most of the failures occur in the upper part, and they nearly always originate from the destruction of refractories by the dust carried by the gas and an obstruction of the flues. High temperature obviously encourages this attack. When the gas is thoroughly cleaned, the attack is negligible and Cowper stoves are known to the author which have operated without trouble for 25 or 30 years at more than 1300° C, with cleaned gas.

For protecting the top of the checkers, especially with stoves operating at high temperatures, Continental builders often use for a relatively low depth what they call 'heating bodies' (*corps chauffants*), i.e. thick bricks. This solution can, in certain cases, be recommended.

CONSTRUCTION OF COWPER STOVES

Steel Shells, Refractory Linings, and Domes

The shells of most Cowper stoves are cylindrical. It is, however, impossible to construct with a shell of this kind a logical insulated refractory lining. In the U.S.A. allowance is generally made for insulating material of constant thickness from top to bottom, which is illogical since the temperatures vary considerably. Continental designers often increase the thickness in the upper part, which means that the brickwork in the hottest part is the thinnest.

The only logical solution is to use a conical shell (*see* Fig. 5). The refractory lining is of uniform thickness and the insulating material increases in thickness. This solution is not new, but a particularly simple method of construction, consisting of plates welded on one another, has been patented. This has the

* D. Petit, *Trans. Brit. Ceram. Soc.*, 1939, vol. 38, pp. 313–327.
† D. Petit, *Rev. Mét.*, 1938, vol. 35, pp. 477–494.

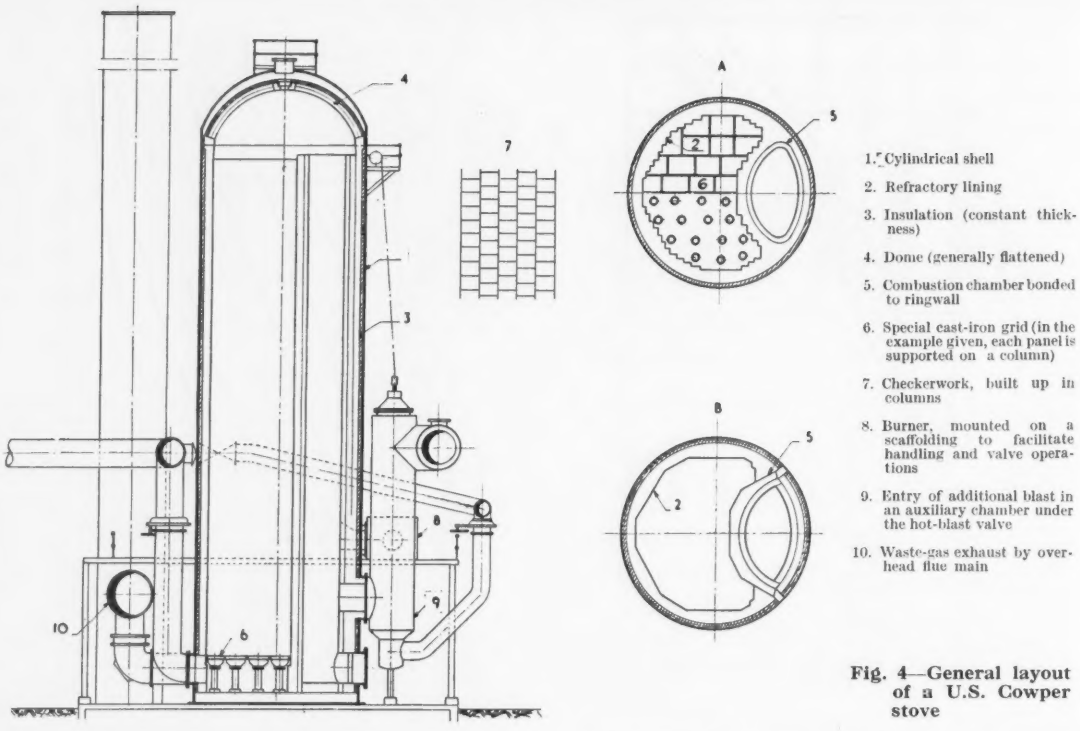

A
B
1. Cylindrical shell
2. Refractory lining
3. Insulation (constant thickness)
4. Dome (generally flattened)
5. Combustion chamber bonded to ringwall
6. Special cast-iron grid (in the example given, each panel is supported on a column)
7. Checkerwork, built up in columns
8. Burner, mounted on a scaffolding to facilitate handling and valve operations
9. Entry of additional blast in an auxiliary chamber under the hot-blast valve
10. Waste-gas exhaust by overhead flue main

Fig. 4—General layout of a U.S. Cowper stove

further advantage of avoiding stresses in the shell, due to expansion of the refractories.

For the same reason, Continental designers often provide between the refractory insulating material and the shell a layer of coarse insulating material (*A* and *B*, Fig. 5). It should be mentioned here that coarse material is divided into annuli to prevent settling.

In Continental stoves, the dome is usually hemispherical. This is a little more expensive, but is more logical from a constructional point of view. In the U.S.A. flattened domes are generally used; they are satisfactory provided that the dome brickwork is sustained by a steel band.

In either case, the dome should be made up of two layers of refractory material and one or two layers of insulating bricks. In all modern stoves, the metal dome is insulated internally, either as in Germany by means of insulating bricks fixed with cement, or as in France with a kind of insulating packing fixed by conventional methods.

These methods are to be recommended, since the dome is the main source of heat losses, owing to the inevitable passage of blast through the refractory dome when the stove is put on blast.

The insulating material used for the ringwall and the dome is briefly of three qualities. On the Continent, diatomite bricks are generally used, and, for thin-walled Cowper stoves which, according to a patented device, can in certain cases be made as a single layer of refractory with especially shaped joints (*B*, Fig. 5), insulating refractory material or U.S. products are used.

The inside of the refractory lining is one of the characteristics which distinguishes U.S. from Continental construction. In the U.S.A. the walls are usually either ridged or polygonal (*A* and *B*, Fig. 4). They are often built with standard refractory bricks.

Continental designers in most cases use a refractory lining with an internal cylindrical section (Fig. 5), sometimes a patented octagonal ringwall, and occasionally a ridged wall.

The advantage of a ridged or polygonal ringwall as used in the U.S., or polygonal as used on the Continent, is in not having to cut the checkerwork to fit on the periphery. On the other hand, the cylindrical construction results in a better utilization of the shell. Cutting the checkers does not matter when they are independent of the ringwall and the combustion chamber.

Combustion Chamber

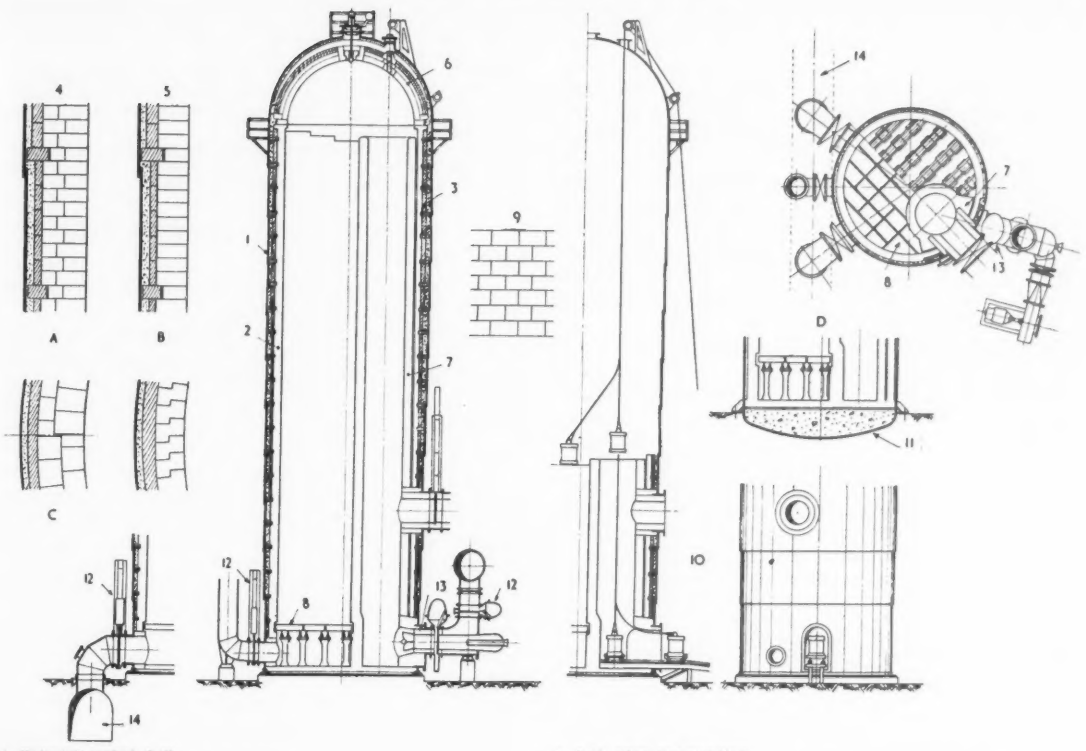
The design of the combustion chamber is very critical in the construction of a Cowper stove.

Standard U.S. practice is to use an elliptical chamber bonded to the ringwall. This is unwise for two reasons:

(*a*) It is a simple matter to calculate the relative expansion between the inside wall of the combustion chamber and the ringwall

(*b*) It is easier still to prove in a stove of the independent chamber type that the chamber ' rises ' 100–150 mm in relation to the wall, and as a result to conclude that it is a mistake to bind together brickwork in which there are differences in expansion.

This disadvantage is overcome in the U.S.A. by using filling to reduce the cross-sectional area of the



1. Patented conical shell
2. Refractory lining of constant thickness
3. Logical insulation (increasing in thickness)
4. Details of normal shell
5. Details of thin shell
6. Dome (usually hemispherical) with steel band support
7. Unbonded combustion chamber (usually cylindrical)
8. Grid, often free-standing
9. Details of bonded or interlocking checkerwork of free-standing type
10. Use of combustion chamber as charging hoist and patented oval aperture
11. Detail of patented concave-bottom
12. Automatically controlled valves
13. Burner with independent blower
14. Waste-gas flue (usually underground)

Fig. 5—General layout of a Continental stove

checker chamber; this is not a profitable solution. On the Continent, the problem is solved by using in most of the stoves a cylindrical combustion chamber, independent of the wall; for the remainder, an elliptical chamber is used, which should also always be independent.

The cylindrical combustion chambers are the more stable of the two. It is sometimes said that the distribution of the gas in the checkers is less than with elliptical chambers. In fact, the distribution is satisfactory in all modern stoves which do not have interconnecting flues.

Space does not permit a more detailed discussion, but it can be said that, in modern Cowper stoves, the upper part of the combustion chamber should be made of super-duty materials consisting of at least 85% chamotte (grog) and consequently having a very small shrinkage. Under these conditions, a properly constructed combustion chamber will remain vertical and will not break away from the shell.

Grids

Only brief mention of grids will be made here, since this subject will be dealt with again later in the book.

In all Cowper stoves, the grids are of cast iron; on the Continent, hematite iron is used; but in the U.S.A., in large capacity-stoves, special irons are used, capable of withstanding temperatures of 400–500° C. Figure 5 shows a U.S. grid in which each element is supported with a separate column.

Burners and Valves

In modern Cowper stoves, both in the U.S.A. and on the Continent, burners with their axes perpendicular to the axes of the combustion chambers are used. They are often fitted with a device, which will not be described here, for regulating the combustion. In all modern installations, each burner is supplied with a separate air blower.

From the point of view of valves, U.S. burners are still very primitive. On the Continent, the burners generally include a single burner shut-off valve (*see* Fig. 5) and a valve for gas. In most modern stoves on the Continent, the burner is mounted on an oval plate, as shown in Fig. 5; this patented method is excellent (*see* section on " Erection ").

The hot-blast valves are also arranged in different ways in the U.S.A. and on the Continent. In the U.S.A. mushroom valves (Fig. 4) are most often used, situated in a subsidiary chamber; the addition of cold air is made below these valves in such a way that they operate at a uniform and relatively low temperature. On the Continent, the valves are located in the primary blast; they are usually water-cooled and are

of the vertical type, as shown in Fig. 4. There are advantages and drawbacks to each method, which will be referred to in the book.

The waste-gas valves are also very differently arranged in the U.S.A. and on the Continent (*see* Figs. 4 and 5). The same applies to the cold-blast valves.

One important question concerning these last two types of valve is that of the pressure and decompression devices. This is of particular interest in modern stoves which can be operated at high pressures. These two operations can be carried out with ancillary valves, of 300–400 mm diameter, or with small sliding devices attached to the valves.

There are many ways of disposing of waste gases. On the Continent, an underground flue is generally used (Fig. 5) but in modern U.S. installations an overhead flue main is often used (Fig. 4). Both arrangements have their advantages and drawbacks which will also be referred to in the book.

Use of the U.S. valves has led on the other side of the Atlantic to a general stove layout (Fig. 4) which is very different from that in Fig. 5. In the U.S.A. control is always manual, but on the Continent over half the installations, and more than three-quarters of modern plants, have automatic control. The operation of a lever is enough to carry out all operations in the minimum of time and without the possibility of mistakes. Installations of this kind have been working very satisfactorily for 30 years and it is difficult to understand why U.S. engineers have taken so little interest in them.

It is not proposed to say anything here about instruments for measuring the temperature of the dome; pyrometers of several kinds may be used. Control of combustion is generally desirable, especially if the Cowper stove is used as a pressure regulator.

The question of controlling the blast temperature will be the subject of a separate investigation. It has already been said that the U.S. method seems to be a good one, but it requires one more valve per stove. Continental operators are content to inject the air into the end of the hot-blast main, sometimes near the furnace.

COWPER STOVES TO-DAY AND TO-MORROW

RESEARCH ON THE BEST PRESENT-DAY STOVES

Figures 4 and 5 show the present arrangements of Cowper stoves used in the U.S.A. and on the Continent. It is proposed to give a brief survey to determine the fundamental differences between them; some personal opinions will be added:

(1) Well designed modern checkers are clearly more effective. They are more suitable for heat storage, which is bound to develop in many works. They should be built up of interlocking or bonded blocks with modern refractories, manufactured 'dry.' Modern checkers are also better fitted for high temperatures.
(2) The steel shell should preferably be conical, to permit suitable insulation to be constructed.
(3) The dome can be flattened or hemispherical, both methods having their merits. The dome shell should be internally insulated.
(4) The combustion chamber can be cylindrical or elliptical, but it must be completely independent of the refractory lining and built with great care.
(5) Any kind of grid can be used; it is better if it is independent of the ringwall.
(6) The burner should be mounted on an oval plate, which adds little to the total cost and makes mounting and maintenance easier and more economical.
(7) Automatic control is generally recommended, and its use will certainly be extended, especially for the large-capacity stoves (*see* below).

FUTURE ADVANCES IN COWPER STOVES

Large-capacity Stoves

The largest Cowper stoves are usually about 8 m in diameter and 33–35 m high.

On the Continent, stoves are designed with a heat capacity which is sufficient to supply the blast at 1000° C to blast-furnaces consuming 700–800 tons of coke per day. These conditions are no longer applicable with furnaces consuming 1200–1500 tons of coke per day. How, then, are such furnaces to be supplied ?

In the U.S.A. reversals are carried out every 1½ h, accepting the fact that the waste-gas temperature will be 400–500° C. This solution leads to low efficiencies, and there is also a danger of damage to the checkers due to their subsiding under load when hot. There is no doubt that this practice is in any circumstances inapplicable in Europe.

The solution to the problem is simple. Standard-size stoves with modern checkers may be used, and reversals must be more frequent, which unquestionably calls for the application of automation. With a shell 8 m × 33 m, a blast-furnace using 1500 tons of coke per day can be blown, for example, at 900° C and with an efficiency of about 90%, provided that the reversals take place every half-hour; for a blast temperature of 600–700° C, they should be made every 45 min.

Stoves Operating at Very High Temperatures

Normal Cowper stoves are defined as those which operate between 700° and 800° C; those which function between 900° and 1000° C are high-temperature stoves, and very high-temperature stoves should reach 1200–1300° C with the dome at 1400° or even 1500° C.

The advantages of using very high-temperature stoves are, firstly, that further economies in coke could perhaps be made, and secondly, that the stoves could store heat, even with high-temperature blast.

The author is fully aware that to think in these terms will provoke criticism from some engineers. However, in 20 or 30 years' time it is possible that these temperatures will be considered normal.

At the present time, without any special dispositions, the maximum temperature of the dome is often 1200° or 1300° C, which corresponds to a blast temperature of about 1000° C, a temperature which is at present reached in many works, especially in those making manganese irons. To exceed these temperatures, it will be necessary, with normal gas, to pre-heat the combustion air, and perhaps the gas, using a patented process.

As far as the refractories are concerned, there are no difficulties, except for one part of the checkerwork, but the refractories industry has made such progress in the last twenty years that it is sure they will finally solve this problem.

High-pressure Stoves

High-pressure stoves are at present fashionable, with back-pressure either in use or under consideration. So far as is known, no special arrangements are used for this purpose in the U.S.A.

Continental operators, rightly or wrongly, are more circumspect. Many modern stoves include a patented concave bottom with special arrangements for balancing the pressure (*D*, Fig. 5). The valves are sometimes made of cast steel.

Stoves without Combustion Chamber

This has been the dream of many stove builders for a very long time. For various reasons, it has not yet been applied, at least to the author's knowledge.

As things stand at present, it should be technically possible to do so, and discussions are going on with metallurgists for manufacturing the refractories and the equipment to build such an installation.

Use of Gas Turbines

This paper would be incomplete without a reference to this possibility, which will be studied by the author in a future paper.

CONCLUSION

In these days of international co-operation, it would be interesting for blast-furnace operators and Cowper stove builders to get together round a table with the object of improving the construction of these stoves, which play such an important part in the consumption of energy throughout the world. For more than 30 years, the design of stoves has been unchanged, save in a few details.

We have done our best to collect together what is best in present installations, and ways and means of perfecting them have been indicated in this paper.

The best tribute that could be paid to Edward Alfred Cowper would surely be to profit from the centenary of his patent by trying to take his invention a stage further as a result of international co-operative research. The present time is especially favourable for such a meeting because many blast-furnaces are being built to economize in both coke and energy.

Acknowledgment

The author is indebted to the Institution of Mechanical Engineers for permission to reproduce the portrait of Cowper which faces p. 502.

Report on

Latin American Meeting of Experts in the Steel Making and Transforming Industries

SAO PAULO, 1956

The following is a general summary of the proceedings and discussion at the Latin American Meeting of Experts in the Steel Making and Transforming Industries, held at Sao Paulo, Brazil, from 15th to 28th October, 1956, under the auspices of the United Nations Economic Commission for Latin America. It is reproduced in the form in which it was presented by Mr. H. W. A. Waring, Managing Director of Brymbo Steel Works Ltd., in his capacity as General Rapporteur, on 27th October.

IN THIS DOCUMENT an attempt has been made to summarize briefly the proceedings at the meeting. In a document of this character it is clearly impossible to go into detail, but it may serve to draw attention to the salient points.

At the opening session a statement was made by Dr. R. Prebisch, the Executive Director of E.C.L.A., which set out very clearly the reasons why the expansion of Latin American steel and transforming industries is essential.

Clearly, the expansion of Latin American steel production and transforming industries is an economic necessity, and the vital questions which the meeting has considered are what methods of production and what technical improvements will give the best results, together with some attempt at an economic evaluation of the effects of this expansion.

As regards steel production, Latin American countries are, in the main, handicapped by lack of suitable coal; on the other hand they have considerable advantages in the availability of high-class ore. In an expanding economy scrap is always liable to be in short supply and therefore the demand for iron ore and coke will be high, which involves the provision of adequate coke-oven and blast-furnace capacity.

Mr. Waring was elected rapporteur of the Latin American Meeting of Experts on Steel Making and Transforming Industries organized by the United Nations Economic Commission for Latin America and Technical Assistance Administration, in co-operation with the Associaçao Brasileira de Metais, held at Sao Paulo from 17th to 27th October, 1956. His report forms Part II of the general report of the Meeting, shortly to be published by the United Nations.

The complexity of the steel transforming industries makes consideration of this subject and the drawing of valid conclusions particularly difficult, but a start has been made. At the first meeting of this type held in Bogotá in 1952, particular attention was paid to steelmaking, but in this meeting only specific aspects of special interest have been covered, whilst a substantial portion of the meeting has been devoted to a first approach to the technical and economic aspects of the transforming industries.

The meeting discussed various methods of iron and steelmaking, including sections on reduction furnaces, the use of oxygen in steelmaking, rolling mills, and non-current steels. It then considered the training of personnel for the Latin American steel transforming industries, a subject of vital interest in view of the rapid expansion taking place and the need for an enormous increase in the quantity of skilled labour required.

The second part of the meeting, which was a new departure in Latin America, was concerned with the economic and technical aspects of machining: the economic evaluation of steel transforming processes and the economic and technical aspects of forging and casting. Attention was then given to raw-material requirements; this was followed by consideration of machine-tool and road-vehicle manufacture. The meeting concluded by discussing the integration of industrial resources and development problems of other mechanical industries.

The problems of highly industrialized countries and those which are in the course of a greater or lesser degree of industrial development are naturally somewhat different. In the industrialized countries a pattern of production has been evolved over the course of years, but this has grown up somewhat haphazardly. The Latin American countries can benefit from the experience of the industrialized countries, not only as regards the technical and economic aspects of various types of processes employed, but also by learning lessons from the errors committed in the past in the industrial planning of countries outside Latin America. The consideration of and the free discussion of these problems are among the major reasons underlying the calling of this meeting.

No doubt each of the countries present, and in fact each of the individual representatives of these countries, will to a certain extent draw their own conclusions from this meeting and apply them when considering present and future planning in their individual countries, and in the industries with which they are primarily concerned.

In view of the widely different conditions which prevail from country to country, even a simple summary of the findings of the meeting is difficult, but in the following paragraphs a number of points have been drawn from the draft reports prepared by the discussion leaders and secretaries of the groups referred to above.

PRINCIPAL POINTS FROM REPORTS OF DISCUSSION LEADERS AND GROUP SECRETARIES

IRON AND STEELMAKING

Desulphurization

The elimination of sulphur from pig iron is a subject of major interest in Latin America, as the majority of indigenous coal has a somewhat high sulphur content. Elimination of sulphur from pig iron can be carried out:

(*a*) In the blast-furnace
(*b*) In the course of intermediate operation between the blast-furnace and the steel furnaces
(*c*) In the steelmaking furnaces.

Although the choice of the actual method to be adopted is a matter to be decided by each individual, country, and company, it should be emphasized that the documents presented all drew attention to the fact that it is possible to increase the output of blast-furnaces by operating with a minimum of slag and a lower basicity index, which also results in saving coke. The resulting pig iron would, however, have a higher sulphur content than when operating with a large slag volume and a high basicity index.

Various methods of desulphurization by intermediate operations were considered. The extent to which these should be used in any particular plant must depend on consideration of output versus cost.

It was emphasized that only processes which have been tried and proved industrially should be adopted, even if less well known processes might appear less costly. On the other hand, in certain cases, in view of the necessity for maximum production from the blast-furnaces, even if desulphurization outside the furnace should prove more expensive, it may be advisable to adopt it.

Furnaces

The development of electric low-shaft furnaces for pig-iron smelting, the international low-shaft blast-furnace, and electric-arc furnaces were discussed.

In the field of pig-iron production, it appeared that, whilst the electric low-shaft furnace had been commercially developed, and could be used with either a mixture of coal and anthracite or with charcoal as a reducing agent, certain limitations still existed as to the size of the unit. Development work on other types of low-shaft blast-furnace appeared to have been mainly directed towards the use of low-grade ores and poor-quality fuels.

Electric melting furnaces of various types were also discussed and attention was drawn to the benefits of making special and alloy steels in these types of furnaces.

Use of Oxygen in Steelmaking

The advantages of the use of oxygen in steelmaking were generally accepted, but it was felt that a systematic study of the cost of production of oxygen was necessary, and it was suggested that this should be undertaken by E.C.L.A., in conjunction with experts in this field.

As regards the different uses of oxygen in steelmaking, it was not possible to formulate any general rules about the advisability of adopting one process rather than another. In each case this would have to be studied in the light of the phosphorus content of the iron process and the percentage of other metalloids present, and in the light of conditions prevailing or likely to prevail in any given plant.

It was felt that when the cost of oxygen production in Latin America, in varying quantities, had been satisfactorily established, it would be possible to benefit from and interpret more fully the documents presented.

Rolling Mills and Finishing

The problem of steel rolling in Latin America was formulated in a document prepared by General Macedo Soares e Silva and this met with general acceptance.

The main points that were emphasized were:

(*a*) The necessity of providing for successive expansions and of thinking generally in terms of an expanding market

(*b*) The rejection of cheap installations which might have certain preliminary advantages but would soon have detrimental effects

(*c*) Since complete specialization of mills is not normally possible, it was necessary to establish programmes which, without placing too heavy a burden on the initial investment, would allow for the purchase of a primary mill which could provide for future needs

(*d*) Installations should be selected from those already tested, bearing in mind that untrained personnel would be operating the mill in the earlier stages.

It was also emphasized that, as quantity demand is satisfied, quality requirements become higher, and so equipment must be adequate from this angle also.

Since the investment cost of rolling mills per ton capacity in an integrated steelplant represents more than half the total investment, any error in the selection of rolling-mill equipment will be costly. Since, in the main, larger units are sturdier than small ones, this may have a bearing on the cost of down time and maintenance and repair, which may represent a large percentage of total rolling cost.

Continuous casting was considered, and the potential advantages for small Latin American plants were obvious. In addition, continuous casting might assist the production of a primary mill which had become too small to cope with the supply of ingots of normal size. The economical advantages of the process both as regards capital and production costs were outlined. It was felt that, whilst developments in continuous casting should be closely followed, it might be preferable for Latin America to await further progress in other parts of the world, particularly if it were wished to use the process for mild steel as distinct from special steels.

Non-current steels

A number of Latin American countries are in a favourable position to produce non-current steels, owing to their exceptionally pure iron ores and the existence locally of alloying elements.

With rising production, it is necessary :

(*a*) To limit the number of types produced to the minimum possible. In order to achieve this, the problem of definition and classification has to be solved, and it was felt that work in this field should be continued

(*b*) That the number of types produced should be spread over the smallest possible number of mills; a wide common planning of production programmes was thus urgently necessary.

IRON AND STEEL TRANSFORMING PROCESSES

Economic and Technical Aspects of Forging

The emphasis in the papers prepared was on what had been achieved technically in industrialized countries in the field of forging. Included in this was consideration for drop-forging of cost factors and investment and the minimum market demand necessary to justify the installation of the process.

In a transition period, account had to be taken not only of the length of runs, but also of the effect of the existence of the installation on future demand. During this transitional period, normal operational methods might be uneconomic, and processes would have to be adapted to allow for this.

The meeting considered that the evaluation presented for drop forging should be extended to machine forging and press forging. The possibilities held out by the most modern developments in cold forging should also be explored, particularly in view of the savings in raw-material consumption, which might be achieved, and the substitution of cold forging for machining.

Economic and Technical Aspects of Casting

Consideration was given to problems of steel and iron casting, from both the technical and the economic angles. From the technical angle, considerable interest was expressed in the manufacture of nodular cast iron, and it was felt that further study should be given to this subject.

Foundry mechanization appears to be an urgent problem, particularly because of its influence on costs, and it was felt that the advantages in the saving in man hours more than compensate for the cost of installation.

In the main, data on the casting industry was incomplete and it was suggested that studies in this field should continue in order to obtain more knowledge of the capacity and conditions of foundries in Latin America. The development of the industry in recent years has been considerable, and it is considered that the subject is of major current interest, owing to the number of enterprises which are modernizing their methods of production and because of the trend towards the setting up of numerous new enterprises in this field.

Economic and Technical Aspects of Machining

The papers considered in this section dealt partly with technical and partly with technico-economic problems. As regards the economic aspects, this was the first time in E.C.L.A. meetings that an approach had been made in this field and the first objective was to devise means of studying it.

The meeting felt that the provisional approach adopted by the Secretariat, particularly in the two papers prepared by them, was on the right lines, and should be extended to a full-scale study covering selection of types of equipment suitable for Latin American conditions. It was felt that particular attention should be paid to considerations relating to the substitution of human skill by mechanization.

Economic Evaluation of Steel Transforming Processes in Latin America

Rational application of investments is of critical importance when resources available for industrialization are limited, but inadequate statistical data, particularly as regards economic factors and technological coefficients, may limit the development of rational policies within manufacturing enterprises or the carrying out of industrial studies and economic planning. A proposal for a new technique of evaluation was presented to the meeting and discussed. The technique discards the notion of sectors or products and penetrates more deeply into the economic structure by evaluating basic processes. The evaluation of products is, in fact, reduced to determining the composition of the materials employed and their subsequent processing.

The technique offers sufficient elasticity corresponding to the required degree of accuracy. Since evaluation of processes includes complete requirements for input of resources per unit of weight or time, as well as determination of unit costs and selling prices, rapid predictions can then be made for varying degrees of manufacturing integration. In planning the manufacture of a new product, therefore, estimates could rapidly be made covering anything from an entirely integrated operation, from basic materials to final products through cases when manufacturing was complemented by the purchase of semi products and industrial services from outside suppliers.

In all cases, a reliable forecast could be made of the total resources required, such as human services, materials, and investment in plant and working capital, as well as unit costs, level of selling prices, profitability rate at various levels of capacity utilization, growth rate requirements, and the competitive position as regards imported products.

During the discussion, the economists present expressed the view that the proposed technique of evaluation:

(*a*) Was potentially a useful tool in the group of devices employed by planners and business executives, when attempting to predict the possible successful performance of new or enlarged industries
(*b*) Was applicable to situations where an economic evaluation would result in implementation or rejection of a proposed development project
(*c*) Represented a substantial implementation of input–output methods and constituted a valuable instrument for linear programming in some economic sectors.

The industrialists taking part in the discussion agreed with the advantages of applying this method of evaluation to economic control of enterprises and pointed out its originality in the use of costing as a projection for predicting capital structure. It was suggested that:

(*a*) Since the potential utility of this evaluation method was of more than regional interest, it would be advisable if E.C.L.A. would undertake a joint study together with the Economic Commission for Europe and the Bureau of Economic Affairs of the United Nations
(*b*) Experts nominated during the course of the discussion would continue to assist the E.C.L.A. Secretariat, until the evaluating technique acquired its final, usable form.

The application of the system to a pilot study is referred to in the section on road-vehicle manufacture.

Training of Personnel

From the studies presented and the discussions which took place, it was clear that there were serious labour training problems at all levels in the Latin American steelmaking and transforming industries. The urgency of the problem justified the proposal that E.C.L.A. and T.A.A. should be asked to make a wide examination of the situation in Latin America in order to determine the extent of the skilled labour deficit.

It was felt that, in the case of engineers, the following steps might be advisable:

(*a*) Formation of a Latin American specialization centre, making full use of existing institutions (E.C.L.A. and T.A.A. might co-operate with this)
(*b*) Amplification of the scholarships and fellowships systems and postgraduate courses.

Measures which might be taken into consideration to alleviate the shortage of technicians were:

(*a*) The setting up of technical schools in areas where steel transforming industries were established, which would give preference to the training of technicians in metallurgy, machine construction, and electro-technology
(*b*) More extensive use of training within industry
(*c*) Selected immigration of technicians.

As regards skilled workers, the following points were suggested:

(*a*) The development of industrial apprenticeship systems in co-operation with specialized organizations
(*b*) Intensive training of additional workers in special courses and the wide use of T.W.I.
(*c*) The encouragement of skilled labour by means of adequate promotion systems
(*d*) Selected immigration.

The need for instructors led to the following suggestions:

(*a*) There should be an interchange of instructors between various countries, in order to increase their knowledge of various types of industry and by training within schools in the countries visited.
(*b*) The establishment of an instructor training centre for all Latin America by expanding that run by S.E.N.A.I. in Brazil (this might be done in conjunction with the I.L.O.).

In general it was also suggested that the implementation of E.C.L.A.'s technical glossary project would be advantageous for all Latin American countries.

DEVELOPMENT PROBLEMS OF LATIN AMERICA'S MECHANICAL AND METALLURGICAL INDUSTRIES

Raw Material Requirements

It is expected that Latin American steel production will be doubled within 5 years, although consumption will increase by only 46% during the same period. This rate of increase of production, which is much larger than the increase in consumption, is typical of the development of many less industrialized countries. The discrepancy is, however, especially pronounced in Latin America, as a result of the excellent development prospects for steel industries in the majority of Latin American countries.

The development of the mechanical engineering industry in Latin America raises the problem of increased production of non-current steels. It was felt that as capacity of the large integrated plants increases, smaller plants could turn to both special qualities and shapes, although this would necessitate additional investment and additions to their technical staff.

In the course of the discussion of the papers it was clear that more information should be sought, and E.C.L.A. was therefore requested, with the assistance of specialized organizations, to make a study on the following lines:

(*a*) Consideration of the policy of amortization which should be followed by the iron and steelmaking and transforming industries, suitable for the economic necessities of Latin American countries
(*b*) A study of the most effective methods of compilation, presentation and publication of statistics of production, consumption, and trade in steel products in Latin America, together with other types of information on the steel industry
(*c*) A study of the probable market for iron and steel products with a view to preparing projections of the demand for steel. This would involve consideration of methods to be adopted taking into consideration:
  (i) Elasticity of demand in relation to income
  (ii) Elasticity of demand in relation to industrial production
  (iii) Input–output ratios

Machine-tool Manufacture

The relative size of enterprises in Latin America and in other countries was considered, together with the types of machines which should be manufactured in Latin America. No clear conclusions could be drawn about the comparative advantages of large and small organizations but, as regards production, it was considered that the production of heavy special products, highly automatic machines, those with intricate operating mechanisms, and very large heavy or complex machines only manufactured in highly developed countries was not advisable. No doubt the larger and more complicated machines will eventually be made, and it was considered that this could be facilitated by the economic integration of Latin American countries, which would increase the size of the market.

Production would be facilitated if agreements were concluded with foreign manufacturers in order to obtain not only designs but also adequate technical assistance. This could be complemented by the interchange of technicians and could be extended to the sales organizations

of the various firms. The establishment of standards and the selection of suitable types of steel for various forms of production was also necessary. Finally, Latin American producers might complement their own production by using components made more economically by either domestic or foreign manufacturers.

The ownership of patents and trade marks presented a difficult problem, but it was felt that the way could be smoothed by the co-operation of the local machine-tool manufacturers' associations, which should not encourage the introduction of prototypes of machines without a prior manufacturing agreement with the foreign firm concerned.

Technical improvements in machine tools made machines obsolete in a much shorter period than had previously been considered normal and the depreciation policy followed should be such as to cover adequately the replacement of the asset within a reasonable period.

In many Latin American countries the rates allowed by the taxation authorities did not conform with reality, and it was felt that the competent international organizations should undertake a study of this problem and advise on suitable depreciation rates.

Road-vehicle Manufacture

Discussion centred around the general problems relating to road-vehicle manufacture in underdeveloped economies. It was recognized that the installation of such new and complex industries could only take place if there were deliberate measures tending to foster such development. In order to ensure success, and in view of the close relationship with other important sectors of the economy, specifically designed overall measures were necessary.

Although conditions differed substantially from country to country, in the main it appeared that in the case of light and heavy lorries and tractors and ' jeeps ', the market in Brazil and Argentina appeared to be sufficiently large to favour production at reasonable cost, although in the main cost comparisons and methods of evaluation generally were somewhat inadequate for a proper appraisal to be made. On the other hand, passenger car production would seem to merit special caution, since this branch of the automotive industry requires a considerably broader market and much greater facilities in the way of auxiliary mechanical industries.

A further important problem was that relating to the difficulties of reconciling the steadiness of design of vehicles over a long period of manufacture in Latin America with annual changes in the same designs in the foreign parent companies. Because of dependence on imported components this question was serious.

Finally, there were problems relating to raw-material supplies. The creation of an automotive industry implies additional supplies of raw materials and finished products, mainly made of steel. The steel industry and the manufacturers of parts and pieces probably will not create production facilities, with related high investments, before large-scale automotive manufacture has begun.

As a result of the foregoing the following recommendations were made:

Recommendation A

I. In view of the diversity of criteria and the consequent results which these may have in the evaluation of the road-vehicle market and

II. In view of the interest in obtaining these data with greater precision on national and Latin American markets as a whole, as a basis for an examination of the problem of integration of the Latin American road-vehicle market,

It is recommended that E.C.L.A. should undertake a study of the road-vehicle market of Latin America from both national and continental points of view with special reference to the elasticity of supply.

Recommendation B

I. In view of the possible repercussions of road-vehicle production on the economic equilibrium, and

II. The possible repercussions of the demand for steel products on the economic equilibrium,

It is recommended that when considering standardization of non-current steels attention should also be paid to the application of these steels to the road-vehicle industry.

Recommendation C

It is recommended that in the light of the discussions on the road-vehicle industry, and the paper presented on " Economic evaluation of the iron and steel transforming processes in Latin America " a study should be made of the road-vehicle industry in Brazil, using the evaluation system proposed in the paper referred to in order to examine and improve the technique therein described.

Recommendation D

In the view of the wide interest aroused by the discussions on the development of the road-vehicle industry, both for Argentina and Brazil, and also the possible repercussions on the remaining Latin American countries, *it is proposed* that E.C.L.A. should be requested to prepare a study on the road-vehicle industry in Latin America. This study should be an amplification of the ideas presented and discussed in this conference, and should be carried out in conjunction with nominated experts.

Integration of Industrial Resources

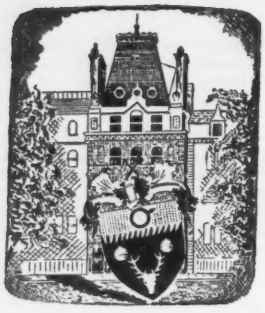
It was considered that some countries had achieved such a degree of progress in industrialization that a new step of a different kind should be taken by pooling resources represented by existing installations, in order to enter into the manufacture of heavy equipment such as that required for steelmaking, pulp and paper, mining, and the manufacture of heavy chemicals. The economic advantages would be savings in foreign exchange and better utilization of existing facilities. Considering that this kind of grouping of industries constitutes an important factor in economic development, it was suggested that development banks and institutions should help and encourage integration. These agencies in turn might request technical assistance from the United Nations.

Medium- and long-term financing on the basis of credits to be obtained from the development and banking institutions was considered. It was, however, essential that, if this credit were to be granted, the locally produced material should be of good quality.

The meeting considered the possibilities of Latin American integration on the regional level, on the basis of a survey prepared by E.C.L.A. The trade committee of E.C.L.A. was to meet in November in Santiago, and the working group preparing this meeting had come to the conclusion that the problem should be tackled on the basis of supra-national or multi-national markets, at least for those products which cannot be manufactured economically on the basis of the demand of a single nation.

The meeting recommended that E.C.L.A. should undertake the study of industrial integration possibilities as a first step towards the preparation of specific projects.

It was considered that in order to achieve Latin American integration, it would first be necessary to standardize and rationalize specifications for steel and for products made from iron and steel, and agree on certain tolerances. It was recommended that E.C.L.A. should study this subject, including the standardization of nomenclature for tariff purposes.



DISCUSSION ON PAPERS

Discussion at Meetings · Written Contributions

Special Meeting in France, 1956

A SPECIAL MEETING of The Iron and Steel Institute was held in France from Tuesday, 5th June, to Thursday, 14th June, 1956, by invitation of the Chambre Syndicale de la Sidérurgie Française and the Société Française de Métallurgie.

A report of the meeting appeared in the January, 1957 issue of the *Journal* (vol. 185, pp. 1–3). Reports of discussions at the Technical Sessions are printed below, except the discussion on the paper " The Effects of Gravity on the Solidification of Steel " which will appear later.

DISCUSSION ON INSTRUMENTATION

This discussion was based on the paper **"Instrumentation in Steelworks"**, *by G. Husson and P. J. Leroy*, which appeared in the May, 1956 issue of the *Journal*, (vol. 183, pp. 56–63).

As the discussion time was limited, Monsieur Leroy's remarks were abridged from the paper as published and have not been reprinted below.

Monsieur **Husson:** I shall limit my remarks to continuous running of the O.H. furnace. For a very long time, operators of these furnaces did not have the measuring instruments necessary to ensure regular control of the furnaces. However, as most of the necessary instruments are now available, it is possible to keep the various factors which come into play at the entrance into the furnace at substantially constant values and therefore the furnace may be operated in the most efficient way possible, subject to leakage which considerably distorts the measurements being made, a problem I shall mention later.

In view of the complexity of the phenomena which occur in O.H. furnaces, I think it is not possible to do away with the personal action of the operator. Even in the U.S.A., it is agreed that no apparatus can entirely replace him and technically, the means of control, even automatic regulators, must permit variation of the operation to whatever extent may appear to the operator to be necessary, but never take the the operator out of commission.

This technical necessity relates also to a human necessity because all apparatus is actually made to assist man and improve rather than worsen his condition. At The Iron and Steel Institute in 1947, Mr. Baker said: "We cannot possibly expect good results unless the adopted methods put into force are not merely followed, but actually adopted by the production crew."

The second important principle to be remembered is that, in connection with all the quantities which can be measured a certain number should be selected, e.g. the principal characteristic variables for control and regulation, so that results may be obtained without complicating the matter by a great many measurements which might interfere with each other and eventually distort the results.

Apart from all additional measurements such as air temperature at the entrance into the furnace, etc., the essential regulations must in my opinion be the following:

(i) Automatic draught control ensuring constancy of pressure in the laboratory

(ii) Regulation of the input of fuel which often may be changed manually according to the initiative of the operator; but a certain number of measuring instruments must be available to him so that he can watch the roof temperature-rise

(iii) Automatic regulation of the air-flow ratio which is fixed at every time of the process according to the fuel, as the flow of atomizing agent if liquid fuel is being used.

Then there is the question why automatic regulation of the pressure on the roof and a manual control of the fuel according to the temperature. I think this is better for these reasons; (*a*) it is necessary to keep the pressure as constant as possible; (*b*) the changes in pressure are too quick to allow a hand regulation to the contrary. As to the temperature of the roof, it is desirable to have a manual control because the right temperature is not necessarily ever the same with different slags; and as the pyrometer cannot control the temperature in all parts of the roof and if the operator is not left some initiative, there may be dangerous hot-spots which are overlooked.

The main factor which must always be remembered is that the best conditions in a furnace at each period of the operation were, till now, not exactly known. Is a long flame better than a short flame? What are the

conditions of the heat exchangers? Our knowledge so far is not sufficiently advanced to answer these questions and, although in France we are carrying on very considerable research work on scale models and actual furnaces, while comprehensive research has been done these last years in the U.K., these problems are a long way from being solved.

Some work on the problem of air-leakage was done a few years ago at the Park Gate Ironworks, where some people believed that it was better to have a constant volume of air, in view of the uncertainty of data on air leakage. In some cases this is justified for the time being, but research along these lines should tend to avoid these leaks and to obtain correct measurements of the volume of air, because without these data really efficient control of the operations is extremely difficult.

Mr. **R. W. Evans** (The Steel Company of Wales Ltd.): It is true to say that instrumentation in steelworks is a good example of a subject which really transcends international boundaries and which must be fully understood by operators of furnaces and converters.

There was a time when it was quite possible to run O.H. furnaces with one instrument and draught control. With the present need to keep them up for so long it has become more necessary to control and measure the various phases of O.H. furnaces.

The only instrument in the first O.H. shop known to me was called a ' reverser indicator ' and each time the furnace was reversed it made a little mark on paper at the beginning and end of every half-hour operation.

It seems that the present tendency to increase production from O.H. furnaces depends on those plants, which are not absolutely new, being able to increase the weight of the charge and, having done that, to maintain the same tap-to-tap time of the furnace so that in proportion the tonnage per hour is increased. This will result in an increase of fuel input more or less in proportion, and this does impose on the furnace structures very considerable temperature stresses which one must be able to measure quite accurately to preserve a structure. It would seem, for instance, there is a limit to the amount of fuel which can be fed to a furnace while keeping a roof on it, for as more fuel is pushed in, the furnace must have a refractory capable of standing up to temperatures perhaps of 1700° or 1800° C if it is to take full advantage of the increased amount of fuel.

Monsieur Husson has referred to the important factor of air infiltration. I believe that an accurate type of preheat indicator recorder, such as a suction pyrometer, used from the beginning of the campaign to the end gives an indication of the combustion air leakage into the furnace. This is a good answer to the problem of maintaining the preheat temperature indication of how much infiltration is occurring if the preheat is maintained. Temperature is as constant as possible. The operator can then preserve the regularity of combustion and the heat transfer on a predetermined plan.

A waste-gas analyser recorder would be important when it is anticipated using oxygen for flame enrichment for it seems that although the amount of ingoing oxygen is measured, it is necessary to know exactly how the fuel is burning in the furnace.

Perhaps in the next few years the O.H. furnace will have a stern fight in competition with other steelmaking processes, and if it is to retain its present position as the best all-round furnace, instrumentation should become as near perfect as possible.

Monsieur **Husson:** I quite agree with Mr. Evans on the opportunity of measuring preheat temperature and air excess in the waste gases, but I know of no suction pyrometer hitherto available for such routine practice.

Monsieur **P. Boutonnet** (Lorraine-Escaut): For a long time the blowers of Thomas (basic Bessemer) steelworks had only empirical tests to control the conversion, because since shortly after its initial invention, the process remained unchanged for almost 70 years, which is surely proof of the genius of its inventors.

But it must be clearly recognized that, in part because of this stagnation of the process, there have been some adverse opinions on the quality of steel worked in a converter. Those of us who have used Thomas steels have certainly had satisfactory results, but general progress of technique has lead to repeated demands for improvements which may have brought some users to call on Martin steel, while at the same time it happily allowed Thomas steel to make a new start. But progress which is being made has only been possible through the development of measuring apparatus such as had been shown at this meeting.

Metallurgists of IRSID have concentrated on giving the makers of Thomas steel the means of greater control which enabled more thorough regularity in manufacture. These concerned the control of blast by the volume-debitgraph, and as a result of more accurate study of the profile of the converter, many large projections were limited, thus removing one source of irregularity in the process. They concerned the control of temperature fo the bath, not only afterwards with the immersion pyrometer, but also especially during conversion, with the colour pyrometer. Finally, they concern more accurate judgment of the point at which the process should be stopped by a signal such as given by the opacimeter.

These developments are already under way, and with the aid of new techniques of blowing they will bring further improvements in the control of the Thomas process which will benefit users of this steel.

Therefore we should rectify the wrong judgments that have been made on the quality of Thomas steel, and to say that, due among other things to the measuring apparatus in steelworks using the Thomas process, this steel will not only stay supreme in the various fields where it has been used for many years but will also have many new applications.

JOINT DISCUSSION ON THE ELECTRIC ARC FURNACE

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parentheses):

"Studies on a 10-cwt Arc Furnace," *by W. H. Glaisher, M. Preston, and J. Ravenscroft* (1956, vol. 183, May, pp. 22–41).

"Some Factors Affecting Electrode Consumption in the Electric Arc Furnace," *by D. H. Houseman* (1956, vol. 183, May, pp. 48–53).

The papers were presented by Mr. **W. H. Glaisher** (British Iron and Steel Federation) and Dr. **D. H. Houseman** (Sheffield University).

Mr. **Glaisher:** B.I.S.R.A.'s 10-cwt furnace was installed to study the chemistry, metallurgy, and economics of arc-furnace operation. The last of these items was chosen for the initial studies, since much less work has been done on it in the past. The chemistry and metallurgy are being studied continuously both in works practice and in laboratories.

To enable the maximum information to be obtained, the furnace was designed to be more variable than most of its size; it has a fairly large transformer and provision for varying electrode size and the height of the roof.

The major part of the work described was devoted to the melting period, since in this period roughly two thirds of the electricity and half the time required for the process is used, and it is common to all steels. Attention was concentrated on electricity and electrode consumptions, which account for nearly half the operating cost, and some attention was given to roof wear.

The early work was on the effects of variables such as the weight of the charge, the type of scrap, the effect of starting with a cold furnace compared with a hot furnace, and the condition of the refractories. All of these were found to have effects on electricity consumption, the main item then being studied. In subsequent trials, care was taken to eliminate their influence by:

(i) Standardization of charge weight and type of scrap

(ii) Operating on a continuous basis so that all heats were made with a hot furnace

(iii) Planning the order of heats to avoid bias by changes in the furnace condition.

The trials covered enough heats for the statistical significance of the results obtained to be examined.

During the course of the work, the electrical characteristics of the furnace equipment were rigorously examined to determine the optimum current at different voltages and to study the efficiency at lower current settings.

Of the results, we will consider first the effect of variations in power input. High-power inputs decrease electricity consumption and melting time. To examine further the relationship between these three variables, some heat balances were made, and the reduction in electricity consumption with increasing power input was explained in terms of the reduced heat losses occurring with the shorter melting period resulting.

There was no effect on electrode consumption of the differences in power input used in these trials.

Increased roof wear was found at the higher power inputs and was related to a higher temperature attained by the roof. Roof temperature rises rapidly at the end of the melting period and it is probable that the higher-power inputs would not have increased roof wear had the input been reduced earlier. This would be possible if the roof temperature was measured continuously, but the methods for doing this are not yet fully developed.

The principal effects of a substantial variation in the height of the furnace roof were that, with the higher roof, electrode consumption was increased by about 25%, while the wear of the roof was greatly reduced. This again was related to roof temperature.

With variation in electrode diameter, the most important effect was on electrode wear, which we found to be strongly correlated with the surface area of the electrode exposed inside the furnace.

Considering the applicability of these results to production furnaces, although high-power inputs result in relatively low consumption of electricity in terms of kWh/ton, the total cost may be increased owing to maximum demand charges. Nevertheless, the use of the highest powers may be justified, since they give the greatest production rates.

The detrimental effect of high-power input on roof life could be overcome if continuous roof temperature measurement were practicable. Methods of roof temperature measurement are being studied using Pt/Pt–Rh thermocouples or a radiation pyrometer sighted on the bottom of a closed-end tube projecting just through the furnace roof.

The results on roof height may be largely of theoretical interest, since in most furnaces a high roof is essential to avoid excessive back charging.

The results on electrode consumption show the importance of surface losses and indicate that electrodes should be as small as is practicable to avoid breakage. A method of preventing oxidation of the surface would be most valuable and work is being carried out in the laboratories with this end in view.

Study of the electrical characteristics of production furnaces should prove valuable in increasing electrical efficiency.

Dr. **Houseman:** The second paper of this session describes tests carried out on two almost identical basic electric-arc furnaces making plain carbon, low-alloy, and manganese steels by a single slag process with a tap-to-tap cycle of about 2 h.

Production demands were such that the furnaces were normally shut down on alternate nights and were working 40 hours out of 48; they were also shut down at weekends. The figures obtained for power and electrode consumption are thus approximately true for continuous working conditions.

It is well known that the efficiency of the steelmaking process can be influenced by many factors. This work examines one only, namely electrode resistivity. It proved, however, to be an important factor and has led to considerable savings in cost per ton of steel produced.

Two major conclusions are drawn from this paper and Fig. 4 illustrates the first; namely, the direct relationship between electrode consumption and mean resistivity, amounting to a difference of about 2·5 lb/ton or about 3*s.* 6*d.*/ton between the extremes of resistivity normally encountered.

The next and most significant test was to apply the data shown in this figure to long-term furnace trials. This we did by collecting low-resistivity electrodes until we had sufficient to run both furnaces for about four months.

The average resistivity of these electrodes was about 875 $\mu\Omega$–cm and Fig. 4 indicates that these should result in an electrode consumption of about 10·75 lb/ton. In fact, the 15 weeks' trials did give (Table IV) an average consumption of 10·65 lb/ton, thus fulfilling expectations and producing an appreciable saving in cost.

As indicated in Table V these savings may have to be offset slightly owing to an increase in power consumption. Since the increase is small and scarcely greater than the accuracy of the wattmeters used, this cannot be regarded as a firm conclusion—it is, in fact, probably a rather pessimistic forecast.

Having shown the possibilities of using only low-resistivity electrodes, we next wished to put the whole matter on a routine basis by instituting some form of acceptance test. We therefore developed a quality control test based on the determination of the resistivity of samples drawn from each batch of incoming electrodes and that control test is now in use in regular production.

Finally, I should like to point out another advantage of resistivity control which, because of production demands, we could not exploit. This consists in the sorting of electrodes into closely graded batches on a resistivity basis and using these batches in trials on other steelmaking variables without fear that the results will be nullified by inherent variations in electrode quality.

Mr. **D. F. Campbell** (Electric Furnace Co., Ltd.): It is appropriate that this paper on the Héroult arc furnace should be discussed in Paris because it is a furnace of French origin. It is also interesting to note that at the present time the Americans are celebrating the 50th anniversary of starting the Héroult process for the pro-

duction of steel in the United States, where the output of electric steel has already reached more than 10 million tons per annum.

It was in Paris that Monsieur Paul Héroult first made his experiments which resulted in the production of aluminium by the process which has been adopted throughout Europe. After establishing works at Froges and at La Praz in Savoie for the commercial production of aluminium, he left the further development of this process to industrial people and devoted his energy to the study of electric steel. When the steel process was demonstrated at La Praz, he decided to go to Sweden, Great Britain, and the United States for the further development of electric steelmaking.

The production of suitable electrodes has always been of vital importance for arc furnaces, and it is evident from this paper that the manufacture of electrodes is still not altogether satisfactory, as they are not homogeneous. This is probably because a number of processes are involved, including the calcining of the anthracite, the extrusion of the amorphous electrode, the baking of this product in a reducing atmosphere, and subsequently the graphitizing in an electric furnace. The last operation is the most difficult of all, as the current is passed transversely through the electrodes and, consequently, tends to heat them unevenly.

The B.I.S.R.A. paper has given us a lot of technical information and much food for thought, and I am sure that anyone who is designing and building furnaces will be very thankful for this information.

In a steelworks there are, however, certain considerations which may influence the ultimate decision about the power of transformers and size of electrodes, such as the terms of power contracts, and the necessity of making the highest quality of steel with some profit. The power to be used on the furnace must be determined after choosing the quality of steel to be made and after the terms of the power contract are known. Thus, an 80-ton furnace may be provided with transformers between 20,000 and 30,000 kVA, after consideration of the above factors.

In other words, a middle course must be steered, taking into consideration all the relevant facts, and the information included in this paper will be of great value, because definite figures are given about various questions which have been the subject of speculation for many years.

Monsieur **F. N. Pensa** (Société Française de Métallurgie): I would mention that the behaviour of the arched roof is affected not only by the distance between it and the bath, but also by the pitch circle diameter of the electrodes in the furnace laboratory and by the diameter of the electrodes themselves.

To avoid localized over-heating of certain parts of the lining, furnace constructors have adopted a pitch circle diameter corresponding to something near the formula:

pitch circle diameter = radius of the furnace shell at the bath level × 0·735.

This rule can be modified in practice, particularly when applied to furnaces of 20 tonnes and over, which require very specialized study on this point.

The diameter of the electrode used on an electric furnace is dependent on both the current per phase and on the capacity of the furnace, and, therefore, on the size of the shell.

On very high power furnaces, a high secondary voltage is essential and consequently the reduction of current per phase which results from it permits the use of a weaker section of electrode.

In this connection, it will be noticed in many cases that a furnace, for example of a nominal capacity of 20 tonnes, corresponds to charges now current in steelworks of 30 and even 40 tonnes, although this is not recommended. The shell diameter is, in effect, determined largely by the bulk density of the charge, which is sometimes low, and by the need for a large surface area between metal and slag, to permit quicker refining.

Electrode wear is dependent on surface oxidation and, consequently, the larger the diameter is, the more important is the surface oxidation.

In a particular furnace, it is always possible to use two and sometimes three different electrode diameters, the sizes of electrodes made and the permissible current densities making this possible.

The nature of the heats and the metallurgical practice sometimes influence the steelmaker in his choice, whether it be in favour of the smallest or the largest possible electrode diameter. Both may have their advantages and disadvantages, particularly with regard to the mechanical strength of the electrodes, and this is irrespective of all considerations relative to the phase current.

When the electrode is of a very large diameter in relation to the furnace shell, one must find a compromise for the determination of the pitch circle diameter in the furnace laboratory, as in the case of the use of Söderberg electrodes to give the best possible protection to the lining and the roof.

With regard to the paper by Dr. Houseman on electrode resistivity, I thank Mr. Campbell for his remarks on the inevitable variations in electrode resistivity from one extreme to the other, and I would add that it is very difficult to determine it accurately, since it varies not only along the length but also across the width.

Speaking from an industrial point of view, for a given diameter of an electrode of good manufacture, these variations in resistivity do not affect the specific consumption of electrodes and, as the speaker told us, the consumption figures can only be determined by very long periods of use. The differences in consumption that he has quoted between electrodes of normal manufacture and electrodes selected on a resistivity basis do not justify either the specification of a low resistivity, sometimes unproducible excepting in special manufacturing processes on a laboratory scale, or the inconvenience to the user of measuring the resistivity.

On the other hand, three factors greatly influence electrode consumption on the industrial plane:

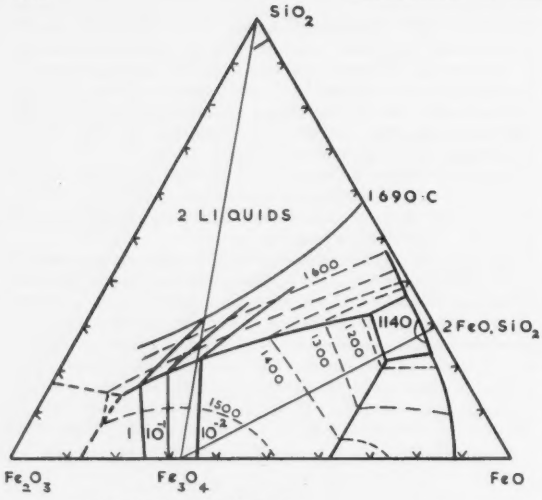
1. The oxidation factor, which is well known and which I will not, therefore, develop here.
2. The factor of breakages in use, breakages due to handling or to purely mechanical effects, such as regulation, which can always be remedied.
3. The cracking and breaking of the electrode in the arc (often difficult to detect), these two causes having a direct relationship to the electrode's resistance to thermal shocks.

The case considered by the speaker concerns a small hand-charged furnace in which there are no thermal shocks comparable to the enormous instantaneous variations of temperature which result from mechanical charging (very often several charges per cast).

In the ordinary working of a furnace, with electrodes of large diameters (400, 450, and 500 mm), specially made, and of a fine close-grained texture, of very low porosity and very low resistivity, these electrodes did not resist thermal shocks.

On the other hand, electrodes with the same diameters, but of coarser grains, of greater porosity and a slightly increased resistivity than the others, broke up very seldom in the arcs and did not crack. As Mr. Campbell has said, the techniques for the manufacture of electrodes in graphite are extremely complex.

I would add that the raw materials used for the manufacture of synthetic graphite, although carefully selected and controlled, are not always 100% reliable, if



Isotherms on liquidus surface
Liquid phase under various oxygen partial pressures

Fig. A—System FeO–Fe_2O_3–SiO_2

one takes into account the allotropic transformation of amorphous carbon to graphite at the very high temperatures of the graphitization furnace, and also the delay of several months which elapses between the date of the beginning of manufacture of the electrode and the end of its use; this makes the investigations still more difficult.

The desire for very low resistivity on the part of the electrode manufacturer can lead to an over-rapid graphitization, which inevitably reduces the mechanical strength of the electrode.

Turning to the industrial scale, since the principal aim of the papers we have just heard is the reduction of the net cost of steels produced in the electric furnace by means of a smaller specific consumption of electrodes, I would like to emphasize that the most important economies possible lie in the reduction of breakages.

In this connection, conditions of storing and handling greatly outweigh all other considerations, without ignoring the importance or evidence of many other factors.

Mr. **Glaisher:** Mr. Campbell mentions power contracts. We realize in B.I.S.R.A. that this is very important; one has to pay more because of maximum demand charges per kW. However, increased production may offset increased costs due to the use of a higher power.

In reply to Monsieur Pensa, I think both the spacing and diameter of electrodes depend on scrap used. With heavy scrap in large pieces, larger electrodes are necessary to avoid breakage; with very heavy scrap, electrodes must be set further apart, so that there is less chance of large pieces remaining on the sides of the furnace.

I imagine that furnace manufacturers have a formula for relating electrode and furnace diameters; they will presumably take into account the type of scrap and the output required.

While agreeing with Monsieur Pensa that storage and handling are factors which affect electrode consumption, I do not regard them as being as important as some of the conditions in use, particularly the area of surface exposed to oxidation inside the furnace.

We found that a thermocouple will only last 24–48 h. The calibration changes slowly and after about 48 h we felt that it was not safe to use it any further. Moreover, the sheath begins to be permeated by iron oxide, and it usually had to be renewed within 48 h. We are now experimenting with silicon carbide sheaths which we hope will have a greater life.

CORRESPONDENCE

Dr. **Houseman:** On p. 34 of the first paper, the authors describe the interesting experimental observation that a silica roof may, under some circumstances, actually increase in weight slightly during its life. The circumstances appear to be those associated with low-power input, where roof temperature does not exceed 1450° C. With high inputs, giving roof temperatures of 1600° C or greater, no increase in weight is observed.

The authors suggest that this increase may be due to iron oxide pick-up and this agrees with the observation of Brampton, Parnham, and White* that the fume formed during the oxidizing period in a basic electric arc furnace, though small in total amount as compared with the reducing period, was nevertheless high in iron oxide content. It is interesting to examine further the possibility of iron oxide pick-up in the light of the phase diagram of the system FeO–Fe_2O_3–SiO_2. Figure *A* shows some aspects of this system and is adapted by White† from a recent paper by Muan.‡ It shows the composition of the liquid phase at liquidus temperatures that result under various oxygen partial pressures. White discussed the problem of flux penetration into silica bricks at some length and, following him, if we neglect the small quantities of alumina and lime that are present in a silica roof brick and regard the working face simply as being composed of iron oxides and silica, then, for an oxygen partial pressure of $\frac{1}{10}$ atmosphere (roughly that obtained in practice during the melt-down period), the composition of the saturated liquid phase lies along that portion of the isobar, marked 10^{-1} in Fig. *A*, that lies in the primary field of crystallization of silica. The equilibrium composition at the working face of the brick will depend not only on the oxygen partial pressure but also on the temperature. At 1600° C much liquid is present which results in considerable penetration of silica-saturated flux into the pores of the brick, together with erosion at a rate chiefly dependent on the viscosity of the working face.

No liquid will be present in this simple system below the temperature at which the 10^{-1} atmosphere isobar reaches the binary eutectic trough (about 1460° C), so that at roof temperatures of 1450° C and below one would expect accretion of iron oxide to occur. In an actual roof the position is slightly complicated by the formation of small amounts of lower-melting liquids due to the presence of about 2% lime and 1% alumina and alkali oxides in the as-fired brick. These will lower the freezing point of the iron oxides to some extent and may thus slow down the rate of accretion.

Finally, it is of interest to calculate the thickness of iron oxide necessary for an increase in weight of 1 lb in the roof. The phases likely to be present under the conditions described are wüstite and magnetite, both of which are of high density. Making an allowance of 50% for porosity resulting from uneven accretion, a rise of 1-lb in roof weight will result from a uniform deposition of a layer rather less than 0·01 in. thick. Thus the observed weight increases of up to 16 lb may reasonably be accounted for on this basis.

Monsieur **J. J. de Jauregui** (Instituto del Hierro y Acero, Madrid): The Spanish Iron and Steel Institute at Madrid have installed a carborundum roof in their 400 kVA ½-ton furnace which operated for some months without any damage. It appears that the extra cost of this roof can be compensated for by the number of casts made possible and the fact that no repairing or changing of the roof is necessary.

* E. C. Brampton, H. Parnham, and J. White: *J. Iron Steel Inst.*, 1945, vol. 152, p. 341.

† J. White: *J. West Scotland Iron Steel Inst.*, 1955–56, vol. 63, p. 99.

‡ A. Muan: *J. Met.*, September 1955, Part 1, p. 965.

STUDY OF AIR FLOW IN MAERZ, SIEMENS, AND TERNI FURNACES

This discussion was based on the paper **"Study on a Model of Aerodynamics of a Maerz-type Open-hearth Furnace."** *by G. Husson, G. Cohen de Lara, and R. Durand,* which appeared in the June, 1956 issue of the *Journal* (vol. 183, pp. 134–145).

Monsieur **G. Husson** (IRSID) presented the paper.

Monsieur **M. Rivière** (IRSID): There seems to be a slight discrepancy between the present paper and the previous work presented to the Congress of the Centenary of the Société de l'Industrie Minérale in Paris last year. You then said that the recirculation under the roof was much shorter in the Terni furnace than in the Siemens furnace. In this second paper you report that the recirculation under the roof is least pronounced in the Maerz-type furnace, more noticeable in the Siemens furnace, while it takes place along the whole length of the Terni furnace.

Monsieur **Husson:** This appearance of a discrepancy is mainly due to the fact that our work is still progressing. All the models we used were 1/10th scale models, but the total length of the furnace room was much shorter in the actual Siemens furnace (9000 m) than in the actual Terni furnace (12,000 m).

We found that the ratio of the recirculation zone to the total length of the furnace seems to be shorter in the Terni furnace than it is in the Siemens furnace. However, subsequent tests have shown that the lengths of the flame, or of the recirculation zone, are not dependent on the length of the furnace, but only on the shape of the burner.

Thus the length of the recirculation zone in a Siemens furnace is *proportionally* larger than that in the much longer Terni furnace, but in a Terni furnace as short as the Siemens type this zone would extend almost the whole length.

Due allowance being made to these facts, the statement in this present paper to which Monsieur Rivière has referred, which reads "... it (the recirculating flow) is very considerable in the Siemens type and can even occupy nearly the whole length of the Terni furnace" means that, for the same furnace space, only the burners being changed, the recirculation zone would be shorter in the Maerz furnace. The difference between the zones in the Terni and Siemens furnace is less than the difference between the zones in the Siemens and Maerz furnaces.

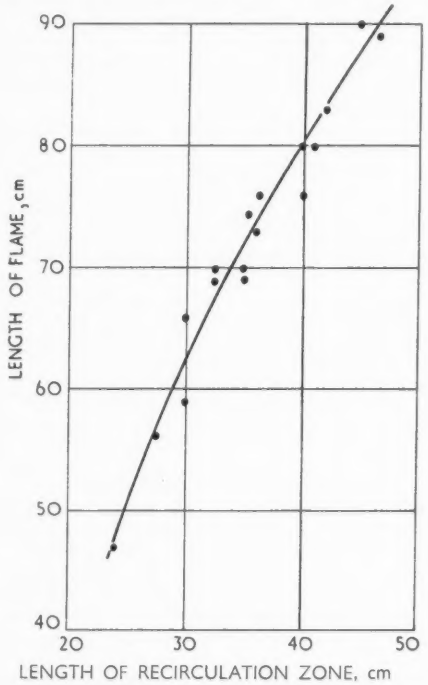


Fig. A—Relation between the lengths of the recirculation zone and of the flame for the Maerz-type furnace

Figure *A* illustrates for the Maerz-type furnace the connection between the lengths of the recirculation zone in the roof and of the flame. The lengths of the recirculation zone are plotted as abscissæ, the lengths of flame as ordinates. It appears clearly that the flame length is closely correlated with the length of the recirculation zone.

Monsieur **A. Mercier** (Directeur Général, Société d'Etudes et d'Entreprises Sidérurgiques, Usines Schneider): Does Monsieur Husson consider that the new type of Maerz furnace will have a different recirculation zone from the present type?

Monsieur **Husson:** Monsieur Mercier is no doubt referring to the new furnaces in Belgium and Germany in which the front and rear walls slope towards the axis of the furnace room, instead of having the rear wall sloping from this axis. Probably this change would affect the recirculation zone favourably but, of course, new tests are required to confirm that the flame would be more stable. Perhaps Monsieur Cohen de Lara would give his opinion on this point.

Monsieur **Cohen de Lara** (Laboratoire Dauphinois d'Hydraulique): If the side walls are inclined, the flame would be more stable, or rather the flame would remain in the axis of the furnace. I consider that the tests already performed have shown that the length of the flame is independent of the inclination of the walls, but the inclination does affect the recirculation currents in the furnace.

Monsieur **A. Grosjean** (Société Cockerill–Ougrée, Liège): Encouraging results have been achieved so far with a 30-ton furnace at Grivegnée in Belgium in which the walls have been sloped towards the axis of the furnace. The output has been increased from 5 to 6 tons/h and the efficiency also improved.

Mr. **R. W. Evans** (Steel Company of Wales Ltd.): We are very interested in the use of cold models for providing basic information for scale-model trials. Although the predictions are fairly accurate, it is generally recognized that there are some drawbacks to the full scale application of this cold-model work. We have shown for instance that if small quantities of solids are added to the cold model at irregular intervals to simulate scrap being fed to the furnace the flow patterns are considerably modified. These flow patterns are also modified unpredictably when violent reactions occur in furnaces using large quantities of hot metal. Certainly the improved results for a single-uptake furnace were predicted from cold-model work and the application of the single uptake to the open-hearth furnace has confirmed the results. When converting a double uptake to a single uptake it is very important to have the right dimensions to maintain the flame direction and reduce the wear on the roof by carrying out deposition tests on the roof of our cold-model furnace. We have been able to determine which particular type of uptake should give the best results for 200-ton furnaces.

Monsieur **Husson:** I quite agree with Mr. Evans that small scale models cannot be used to solve all problems. These are so complex that we began by simplifying them as much as possible. Now we have to investigate the effect draught of depressions in the furnace and of many

other factors such as the charge in the furnace, as mentioned by Mr. Evans. However, by completing the laboratory tests by trials on industrial furnaces in and out of operation, we hope to be able to answer a certain number of questions fairly quickly. But if we hope to know pretty well in the near future how to vary the length of the flame, we do not know at all which type of flame to use at different stages of furnace operation. Professor Thring has shown that a long flame is most suitable after melting, but we have not known exactly until now which conditions are best during the melting time.

We may be able to obtain some information on this point by comparing the results on different lengths of flame on small-scale models with the results on industrial furnaces.

DISCUSSION ON DESULPHURIZATION

This discussion was based on the paper "**Desulphurization of Liquid Pig Iron by Blowing with Lime Powder,**" *by B. Trentini, L. Wahl, and M. Allard*, which appeared in the June, 1956, issue of the *Journal* (vol. 183, pp. 124–133).

Monsieur **M. Allard** (IRSID.): The Chairman (Mr. Mather) has emphasized the importance of desulphurization; we thought that all steelmaking engineers who use liquid pig iron could make use of this report so as to take the desulphurization as far as possible at the time when the presence of carbon in the metal has given greater activity to the sulphur.

Monsieur **B. Trentini** (IRSID): The excellent desulphurizing properties of solid lime are well known in the iron and steel industry and many tests have been made in this connection, particularly in regard to the suspension of the lime in a gaseous current and blowing it into the metal to be treated.

The new desulphurization process which we will describe was developed after many tests at the pilot station of IRSID in St. Germain-en-Laye and at the Pont-à-Mousson factory of the Société des Fonderies de Pont-à-Mousson.

One of the characteristics of this process is that it creates excellent conditions for contact between the metal bath and the desulphurizing agent. This is done by combining two methods:

(i) by using very fine powder
(ii) by blowing it into a gaseous current through immersed tuyères.

This permits a high rate of desulphurization in only a few minutes.

Blowing in powdered lime, particularly when finely powdered, raises a difficult technological problem on which we had to work a long time before we could get it properly developed and we want to thank Monsieur Planiol for his help in this field. The apparatus which we used during those tests is shown in Fig. 1 of the paper.

The column is about 4 m high with a cone at the bottom connecting with the piping which goes to the plants. This apparatus allows regular feeding of the powder and particularly finely powdered lime (e.g. less than 100 μ). The concentrations obtained are very high, at least 38 kg of lime/m^3 of blown nitrogen (about 2 lb/ft^3).

Figure 2 shows a series of four tuyères which discharge very finely powdered lime, in suspension in the nitrogen current, into free air. The concentration is 20 kg/m^3 of nitrogen. We made our first test on a small 300-kg converter in a pilot workshop at IRSID. The second stage was carried out with a slightly greater quantity of metal on a 2·5-ton converter at Pont-à-Mousson.

To avoid the loss of heat which occurs if you have to transfer the pig iron into an additional apparatus, we subsequently used a 2·5-ton ladle with tuyères, in which we carried out the desulphurization treatment and in which also the pig iron was transported. When the ladle is in position for pouring or for transportation, the tuyères project outside, and it is merely necessary to rotate the ladle for them to be immersed while you are blowing the lime.

We shall very soon be putting into service at Pont-à-Mousson a 15-ton ladle based on the same principle.

Our desulphurization tests were made on pig iron of very different types, e.g. basic Bessemer, semi-phosphorous foundry iron, hematite iron, and also high-nickel iron.

Before treatment, the sulphur content of these pig irons varied very widely since we have desulphurized iron and pig iron with up to 0·300% sulphur. Temperatures have varied from 1200° to 1400° C, according to the nature of pig iron used.

Most of the desulphurizing treatments were carried out with powdered lime, obtained from the Mondeville furnaces near Caen, whose lime furnaces are gas-heated. This is therefore an industrial product with a very low cost price, even if we allow for the crushing costs. Figure 4 shows some examples of the grain size of this lime.

These curves give the grain sizes of the lime used in μ. For instance, at least 50% of this powder has a grain size of less than 100 μ and the curve IV shows a lime of which over 90% was less than 100 μ.

Another example shows the evolution of the sulphur during the treatment of 2·500 kg of semi-phosphorous pig iron, 2% of its weight being lime.

The total time of blowing was 3 min and was divided into three 1-min periods. The analysis of the various samples calls for the following comment: starting with the value of 0·095%, the sulphur content of the pig iron has now become only 0·009% at the end of the treatment, which represents 90% of desulphurization. This very substantial desulphurization was brought about in only 3 min.

The carbon, silicon, and manganese contents are reduced slightly between the beginning and the end of the test, and this is due to the various additions of oxygen which are almost inevitable.

For several of these desulphurization tests, we compared the final sulphur content of the pig-iron sample taken out just after the end of the blowing-in to the sulphur content of the sample taken out after a varying waiting period of several minutes, in this case 3 min. Figure 6 shows that there is no blowing-in between these two samples, merely a waiting period, and it can be that the sulphur content is the same. This shows that the sulphurized lime particles are quickly decanted.

Figure 8 shows the rate of desulphurization in 32 tests made on basic Bessemer pig iron containing less than 0·1% of sulphur on the small 300-kg converter at St.-Germain-en-Laye. The blowing-in time was 3 min in every case.

The points have a tendency to approach the asymptote corresponding to the total desulphurization, but there is considerable dispersion and a high consumption of

lime. This is mainly due to the presence of slag from preheating. We could not avoid this during our small-scale tests.

It was found, moreover, that the addition of even a small quantity of reducing agent, such as aluminium, was extremely favourable, because it enabled us to attain more easily an extremely low residual sulphur content, lower even than 0·004%. The corresponding points are indicated by an arrow on the graph, and show that we got very close to the asymptote.

We found that the addition of magnesium gave even better results than aluminium; this was to be expected, since magnesium is known to act at the same time as a deoxidizing agent and as a desulphurizing agent.

The graph shows the comparative results of desulphurization with lime and with magnesium.

Along quite different lines, a series of desulphurization tests was carried out using compressed air instead of nitrogen as the carrying gas. We were thus able to obtain desulphurization above 80%, but it would seem difficult to obtain extremely low residual sulphur contents (e.g. 0·004%) with compressed air as in the previous instances.

The lime collected at the end of the operation is in powder form and is light-brown in colour. As with the Kalling process, it contains a high proportion of metal globules which may even be several millimetres in diameter. Moreover, it is very easy to recover these globules by a cheap process, such as magnetic separation.

The efficiency and rapidity of this process, using a fairly cheap product, allow us to contemplate applying it to very different desulphurization problems, either in foundries to eliminate sulphur from standard pig iron or from special pig iron (e.g. nodular pig iron), or in integrated iron and steelworks where, at the present time, the increased sulphur content is giving rise to considerable technical and economic problems.

Mr. **R. P. Towndrow** (Colvilles Ltd.): The matter dealt with in this paper follows naturally on the subject of the earlier paper presented by Dr. Turkdogan. It appeared to me that the problems associated with attempting to control sulphur content in steel by using different fuel were difficult, and it is necessary to start with the original raw material, namely, pig iron. A cheap and simple process for controlling the sulphur in pig iron would be of great value to blast-furnace operators and would give them considerable latitude in the operation of their furnaces, which they do not have at present.

Many of the processes which have been developed to remove sulphur from the pig iron have been applied to comparatively small batches of 20–30 tons, which is probably very suitable for a plant making steel by the Bessemer process.

In large O.H. shops, where molten metal is required in quantities of up to 200 tons in each batch, it would seem that, in applying or extending some of those processes to the treatment of such large batches, there are difficult problems yet to be overcome. I was interested to hear the comments concerning the substitution of air for nitrogen in blowing; did this result in any substantial reduction in silicon?

We are contemplating a number of processes from blast-furnaces to O.H. plant, e.g. processes for desulphurization and desiliconization and, if some of these processes can be combined in one operation on a large scale, interesting possibilities arise.

Monsieur **Trentini:** As far as the capacity of the ladle is concerned, we will soon begin experiments on 15-ton batches, and we have been asked by a big steel plant to experiment on 50-ton batches.

With regard to compressed air, we found that the loss of silicon in our experiments was small; the silicon was, for example, 1·65% at the beginning and 1·42% after treatment. This small loss of silicon is due to the very high ratio of lime over compressed gas, resulting in a small consumption of gas per ton of iron treated. One can easily calculate that the oxygen coming from the air is often less than the oxygen coming from the unburned part of the lime. However, it seems that it is more difficult with compressed air to go down to very low sulphur contents, such as 0·004%, but we want to check that point more carefully.

Mr. Towndrow's last question is a difficult one: for removing silicon, you need high oxidizing conditions and, for good sulphur removal, reducing conditions and the acid slag from silicon elimination would be dangerous. It is, therefore, not possible to remove silicon and sulphur in the same ladle, if an efficient sulphur removal is desired.

Sir **Charles Goodeve** (B.I.S.R.A.): I compliment the authors on this very important work, which bears some similarity to the work at Union Carbide in the U.S.A. using the more expensive material, calcium carbide. Has a comparison of the two methods been made?

Secondly, was the lime largely retained in the vessel or was it partly lost by being blown out? Finally, regarding the sulphur balance, does any of it escape as sulphur dioxide?

Monsieur **Trentini:** I shall answer the first question later. We have a light cloud of lime coming out of the ladle, but the amount of lime lost in that dust is small, perhaps 1% or 2% of the total lime. We took samples of the dust and found that it had a high sulphur content (about the same as the one in the lime left in the ladle). The calcium sulphide is not burned out to any great extent, and there is practically no oxygen in contact with the used lime.

Monsieur **J. J. de Jauregui** (Instituto del Hierro y Acero, Madrid): What is the cause of the metallic globules which appear in the lime put back at the end of the operation? Could it be that these globules are a result of the reaction of desulphurization, since some of the subsequent reactions could give metallic iron, and that this iron actually appears in the slag? As previously mentioned by Dr. Turkdogan, the reaction of desulphurization liberates oxygen:

$$CaO(S) + (S) \rightarrow Ca(S) + (O)$$

This oxygen reacts with the carbon but mainly with the silicon of the metal:

$$C + FeO \rightarrow CO + Fe$$
$$Si + 2FeO \rightarrow SiO_2 + 2Fe$$

The latter reaction causes a decrease in the Si content of the metal and permits some of the iron to crystallize to an unoxidized form (metallic iron) of a lower carbon content than the original iron. These globules could be found in the slag.

Monsieur **Trentini:** Concerning the iron in the final lime, we found a great deal of small beads in the used lime, as in the case of Dr. Kalling's process. The greatest part of that iron loss is due more to a physical stirring of metal with the solid powder than to a chemical reaction. The amount of iron coming from the metal from chemical reactions previously mentioned is comparatively small.

Dr. **E. T. Turkdogan** (B.I.S.R.A.): If the metallic iron found in the slag were 'metallic shots,' the composition of this substance would have been the same as that of the metal bath. The metallic iron present in the slag, often in a very fine state of sub-division, can be associated with the transfer of sulphur from metal to slag. It is reasonable to assume that sulphur atoms dissolved in iron are ionized, probably having gained electrons from the iron atoms. The experimental evidence indicates that sulphur ions alone do not diffuse into the slag phase across the interface, but that they carry with them surrounding iron cations; i.e. the first stage in desul-

phurizing reactions may be represented by the following equation

$$\underset{\text{Metal}}{[Fe^{++}]} + [S''] = \underset{\text{Slag}}{(Fe^{++})} + (S'') \quad \text{.....(1)}$$

In melts saturated with graphite, the slag may contain some suspended graphite and the following reaction may take place

$$(Fe^{++}) + (O'') + C\,(gr) = Fe + CO\,(g) \quad \text{.....(2)}$$

The metallic iron produced by reaction (2), taking place after reaction (1), should be free of carbon, silicon, etc., which are present in the metal bath. Did the authors make any attempt to separate this iron and analyse it for carbon?

Monsieur **Trentini:** We have not yet done anything on that point.

Mr. **H. G. W. Debenham** (Skinningrove Iron Co. Ltd.): Could you get comparable results by using an ordinary lance immersed in the metal, instead of using tuyeres for blowing gas and lime through the metal?

Secondly, is the vessel used during the desulphurization process acid or basic lime?

Monsieur **Trentini:** I shall answer your last question first: at the beginning, we used a basic lining, but after a few tests we found that it worked as well with a normal fire-brick lining. There is no wear of the lining. With regard to your first question, the use of tuyeres gives a great improvement with far better conditions of contact between lime and iron. We started with lances but we could not get results good enough for a short treatment time and we abandoned them. We made a model study of the two processes, showing that tuyeres give much better conditions of contact.

Mr. **R. Mather** (Skinningrove Iron Co.): One of the big fields for the possible use of such a process is the making of mainly common qualities of steel where it is desirable to reduce the sulphur from, say 0·09% to 0·04%. It would have to be an economical process but it would have a very wide field of application; and, of course, in doing that, such a possibility as is indicated in the paper (namely, that the use of compressed air instead of nitrogen would be possible) would be of great advantage. Correspondingly, the point raised by Mr. Debenham, if one could get something like that degree of desulphurization by lancing from the top, as many of us do with oxygen for desiliconization, would present a great simplification of the equipment.

Mr. **D. R. G. Davies** (Workington Iron and Steel Co.): Does Monsieur Allard consider that, with the more modest aim of sulphur reduction from 0·07% to 0·04%, there is a reasonable possibility of success with simpler equipment such as multiple lances and using compressed air? This would be of great practical importance.

Monsieur **Allard:** We have done experiments on those lines; we shall give the results later.

Monsieur **Trentini:** I will just say a word concerning Sir Charles Goodeve's question about tests made by Hulme and other American researchmen. These tests were made mainly with calcium carbide and I do not recall what the exact figures are; the results were good but calcium carbide is much more expensive than lime, and only a little more efficient. A paper by Hornak and Whittenberger concerning the use of lances to remove sulphur described the use of calcium carbide instead of lime; but the time of treatment was quite long (about 20 min or more) and the efficiency of sulphur removal was not very high.

Mr. **Mather:** This paper has aroused great interest in the British steel industry, because it brings much nearer the possibility of a commercial and economical process for desulphurizing the ordinary grades of steel. Although all the answers are not known at present, this seems a more promising line of development than previous ones.

DISCUSSION ON SULPHUR PARTITION

The discussion was based on the paper "**Sulphur Partition between Gas, Slag, and Metal Phases under Iron and Steelmaking Conditions,**" *by Dr. E. T. Turkdogan*, which appeared in the February, 1955, issue of the *Journal* (vol. 179, pp. 147–154).

Dr. **E. T. Turkdogan** (B.I.S.R.A.) presented his paper.

Monsieur **H. Malcor** (IRSID): Some objections could perhaps be made about the choice of the parameters used by Dr. Turkdogan, but it seems justified by the fact that the representative points on his figures are very well grouped along definite curves. This is very interesting.

Have slags with sodium been studied? At the Salzgitter plant they have been working with very acid blast-furnace slags (CaO/SiO_2 as low as 0·4), but these slags were relatively rich in sodium and the presence of sodium seemed to play an important part in the success of the process. It would be interesting to know whether Dr. Turkdogan has already studied the influence of sodium on the desulphurizing power of blast-furnace slags. Did he study also the influence of spar?

Dr. **Turkdogan:** Good desulphurizing properties of some blast-furnace slags containing soda may be associated with the improved physical conditions of the slag, giving a higher (S)/[S] ratio, and also a higher [Mn]/(Mn) ratio. The chemical properties of slag containing about

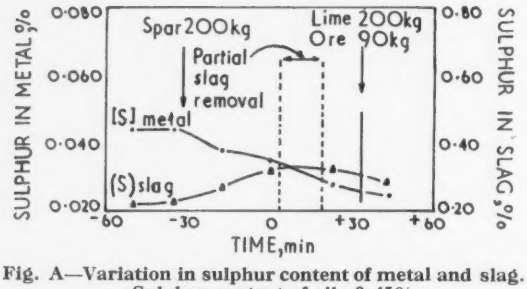


Fig. A—Variation in sulphur content of metal and slag. Sulphur content of oil: 0·45%

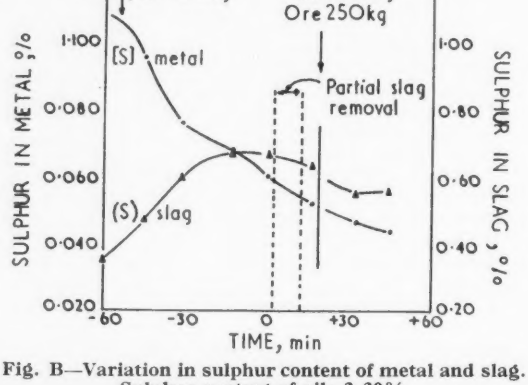


Fig. B—Variation in sulphur content of metal and slag. Sulphur content of oil: 3·30%

Table A
COMPOSITION OF MELTS, %

Heat No.	Sample	CaO	MnO	Total Fe	SiO_2	P_2O_5	Sulphur Content		
							Oil	Steel	Slag
6205	6	46·1	5·2	22	9·3	1·4	0·45	0·025	0·29
6215	6	46·1	5·7	22	9·4	1·5	3·8	0·055	0·63

4% soda should not differ materially from those of similar slags which do not contain any soda. As indicated in the paper, all the basic oxides in complex slags appear to have similar effects on the sulphur capacity of the slag. A few results available on fluoride slags indicate that, under equilibrium conditions, fluoride has no measurable influence on the sulphur reaction.

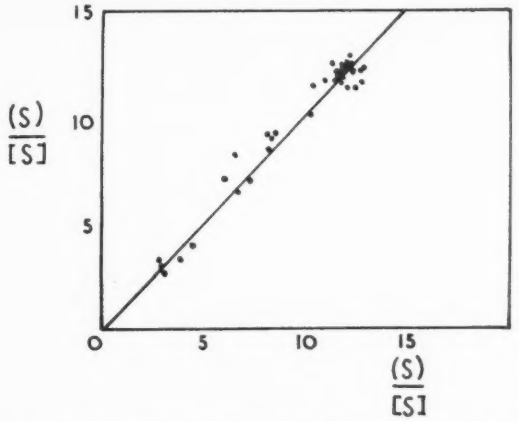
Monsieur **B. Trentini** (IRSID): We made a series of studies of melts to examine the sulphur pick-up by fuel oil in the basic open-hearth furnace. Using fuel oils of very different sulphur content, from 0·5% to 3·8%, we followed the sulphur evolution in the bath, the metal, and the slag, as a function of time at the end of the melting-down period and during the refining period. We found that there is a large difference between the sulphur evolution, depending on the sulphur in the fuel. For example, the curves in Fig. *A* have been obtained with low-sulphur fuel oil.

With high sulphur contents in fuel oil, we get results as shown in Fig. *B*.

At the end of the refining period we have 0·035% sulphur in the case of low-sulphur oil and 0·060% sulphur when the sulphur content of the oil is high. So far as slag composition is concerned, we have low-sulphur slags from low-sulphur fuel oils and high-sulphur slags from high-sulphur fuel oils (compare Figs. *A* and *B*).

In a range of 26 heats with these different kinds of fuel oils we took one heat and a given slag composition, and tried to find out if in the other heats it was possible to obtain a slag of the same composition.

In Table *A* the sulphur partition of slag over metal is, in the first case, 11·6 and in the second case 11·5.



For each pair of similar slag composition, the abscissa is the ratio for the sample with the higher [S], and the ordinate the ratio for the sample with the lower [S].

Fig. C—Sulphur equilibrium in the basic O.H. furnace

Thus two samples from two different heats made with different sulphur contents in the oil will give the same sulphur partition coefficient if the slag composition is the same. That was for a low-carbon steel at a temperature around 1600° ± 20° C.

We examined about 100 samples in order to find pairs of similar slag analysis and the results are shown in Fig. *C*.

We found 36 such pairs and when the results were plotted the points were found to be well fitted around the 45° line. That is not exactly proof, but there is a strong tendency to think that there is a sulphur equilibrium in the basic O.H. furnace, between slag and metal. This confirms entirely Dr. Turkdogan's results.

Dr. **Turkdogan:** I would like to thank Mr. Trentini for his contribution to my paper. It is clear that his experimental evidence supports the view presented in this paper with respect to the state of equilibrium of sulphur reaction in the open-hearth process.

Monsieur **Malcor:** It seems worth mentioning that, during his research work at Hennebont, Mr. Trentini found out that, in the refining period, after melting-down, the total sulphur content of the bath (slag + metal) remained approximately constant, with perhaps a slight tendency to decrease. This fact shows that sulphur is picked out of the flame by the bath during melting only.

Monsieur **Trentini:** Owing to difficulties (of estimating slag bulk, etc.), we are not quite sure enough of our findings to say that there is a loss of sulphur during the refining period: there is either a small loss or no change at all. But there is no sulphur pick-up during the refining period if the same fuel oil is used for both the melting-down period and the refining period. As Dr. Turkdogan has said, we should probably not get the same results using a low-sulphur fuel oil for melting down and a high-sulphur fuel oil for refining.

Solid lime is a very strong desulphurizing agent, and, in the case of a hot metal without silicon, the reaction may be written:

$$CaO\ (sol) + \underline{S} + \underline{C} = CaS\ (sol) + CO\ (gas)$$

Equilibrium calculations show that at 1300° C when iron is saturated with graphite, the equilibrium value for sulphur in iron is only about 0·001%. With silicon in the iron, calcium silicate will be formed, and the equilibrium value will be much lower.

Thomas Eketorp in Sweden has shown that for a normal iron containing about 0·4% silicon, 1·8% phosphorus, 3·3% carbon, and some manganese, the equilibrium value at 1300° C is $2{\cdot}5 \times 10^{-5}$%.

Lime is thus a very strong desulphurizing agent, but this is a little different from what Dr. Turkdogan said, because here we have a solid-slag–liquid-iron process, and all the products stay solid at the end of the reaction.

That means that the activity of CaO remains at unity. And in the case of CaS or di-calcium silicates, their activity also remains at unity. This might be an explanation of the very high efficiency of the lime process compared to a liquid-slag–liquid-metal reaction.

The partition coefficient (sulphur in solid lime)/(sulphur in iron) is much higher in the case of the process of solid-lime–iron reaction than it is in the case of liquid slag, even if it is basic.

At Pont à Mousson in France, by blowing the lime in very fine powder form with nitrogen, we decreased the sulphur from 0·100% to 0·004% or less, in about 3 min with a lime consumption of around 2% of the weight of iron treated.

JOINT DISCUSSION ON IMPACT TESTS

These discussions were based on the following papers (dates of publication in the *Journal* are given in parentheses).

- **"A Study of Impact Tests and the Mechanism of Brittle Fracture"**, *by C. Crussard et al.* (1956, June, vol. 183, pp. 146–177).
- **"Some Effects of Heat treatment and Microstructure on the Transition Temperature of a 0·24% Carbon Steel"**, *by G. Burns and C. Judge* (1956, March, vol. 182, pp. 292–300).

Professor **C. Crussard** (IRSID) presented the paper by himself and co-authors. The paper by Messrs. Burns and Judge was not presented, but correspondence on it is included here.

Madame **A. R. Weill:** Professor Crussard has said that the 'rivers' flow together on the microfaces, and Fig. 27 of his paper shows an example of radiating fracture. Also, he mentioned that there are two types of fracture.

I think it is better in general to avoid the use of the word 'river', for in my experience gained from visual examination of rupture surfaces and their micrographic examination, the 'rivers' flow away to the edge with a radiating fracture, yet examples are shown here where they flow inwards. Would Professor Crussard explain this important point regarding the origin of the fracture and the features of its propagation.

My other point is simply a comparison and an analogy. Perhaps the analogy is not altogether apt, but at least it applies to fractures of β-brasses used as a substitute for soft iron for marine purposes. Now some of these β-brasses show cleavages on their brittle fractures. In such cases it has been observed that the precipitates hinder the propagation of plastic deformation accompanying the rupture. The regions rich in precipitates are marked with traces of cleavage perpendicular to the surface of rupture. These cleavages are short, and curved in the region poor in precipitates which shows that these decohesion markings precede the plastic deformation.

Professor **C. Crussard:** On the first point, I must say that we were not responsible for the term 'rivers' which was used by Dr. Low of General Electric. But on considering the objections that have been made it seems to me that ultimately the term is quite justifiable.

Consider a mountain on which rain falls: rivers will flow away on all sides, then after a certain distance these rivers reunite in the great valleys. This is exactly what happens with the 'rivers' of fracture.

Everywhere they are of local origin, they flow away at the beginning, spreading out in all directions; then, in each 'valley' they merge again.

Madame **Weill:** In general I observe that the rivers flow outwards.

Professor **Crussard:** Never on the surface of the microfractograph.

Madame **Weill:** But as far as microscopic examination is concerned have you not seen radiating fractures?

Professor **Crussard:** Very rarely. It should be noted that when 're-initiation' occurs at some distance ahead of the tip of the fracture, the cleavage and the corresponding rivers merge locally and run backwards from the point of re-initiation. When this process is repeated, the microscopic fracture on the surface is in a way the reverse of average propagation. In this case interpretation may be difficult.

On the second point, it is certain that in ductile cleavage, the accumulation of dislocations, whether a normal build-up on sessile dislocations or whether it is produced by precipitates as has been suggested, may cause, as it has done in the oblique planes, a loss of cohesion in planes other than in those ordinarily followed by cleavage.

Monsieur **H. Malcor:** Have you an exact idea of the initiation of fracture? It seemed clear enough at first, but recalling tests I made a long time ago it seems to me that the metal begins to crack under a very weak force, where it is in contact with the inclusions.

Professor **Crussard:** It is evident that more often there is not a single initiation of fracture but a series of initiations as we have observed in the group of toughened specimens. In these, a series of small cracks appeared at the base of the notch and it was not always the first crack that led to fracture. We had a similar impression in the case of an internal initiation, although this is difficult to observe because one must look at a large surface of the microfractograph, something which is not easy in the electron microscope.

One group of these internal zones of initiation was examined and there was probably one among them which released an 'explosive' force which led to complete fracture, but it is certain that there is a great number of these initiations which have been observed which do not develop at a catastrophic rate. This is what I meant by internal initiations.

Monsieur **Malcor:** You admit that cold working precedes rupture. Is it certain that the early cracks which I mentioned do not appear before any cold working?

Professor **Crussard:** We have not been able to see whether there are cracks in the elastic region. Elsewhere, it seems that the first cracks appear at the edge of the elastic region.

Professor **A. Portevin:** In all these observations and especially in the appearance of multiple cracks, has not the examination been chiefly concerned with the condition of the surface of the notch: with the microgeometrical and physico-chemical states which Charpy examined and which can be removed by electrolytic polishing?

Professor **Crussard:** This is a subject which has preoccupied us but we have not yet been able to take the investigation beyond this point. The number of specimens broken for the test is already very large. This study has been made on about 100,000 specimens, thus providing statistical support for the research. But we are planning a systematic study of the effects of electrolytic polishing.

In spite of this there are one or two points to which we can reply: in the case of different machining techniques we have not noticed any significant difference in

the statistical distribution of results at a given temperature. Naturally, this is not enough; it is now necessary to examine the physico-chemical state of the surface at the base of the notch.

Professor **Portevin:** You have also to consider the cold-working in machining.

Professor **Crussard:** It is very possible that cold working due to machining would have an influence in determining the position of the upper curve which we have termed ' resilient ', in which case the initiation is superficial.

I believe that in the case of the internal initiation which is about 1 mm below the surface, machining will have no influence. It is this upper curve of resilience which by its deplacement through thermal treatment or the effects of machining, etc., principally determines the form of the transition curve.

The President (Dr. **H. H. Burton**): I would like to ask a question relating to Fig. 29 on p. 161, where the two sections of fracture surface are shown after nickel-plating. Is it not a possibility that, in this case, the fracture has taken place along the grain boundaries?

Professor **Crussard:** Yes, on that particular point. It happens from time to time that you will see a part of the fracture following the grain boundary but this is not very common. It is an important thing to remember. In the tensile test we have done at low temperatures we have been able, I think, to show what type of previous deformation is necessary to give rise to intergranular fracture. It seems that a small deformation or a high deformation gives rise to a transgranular fracture, while an intermediate deformation about 5% or 10% prompts intergranular fractures. You have raised a very important point because it gives a clue to one of the important factors of brittleness, which is intergranular stresses.

The **President:** Thank you. I mentioned that point particularly because, in the U.K. there is great interest in this question of intergranular fracture. Some alloy steels are known to be particularly prone to it and intensive research is being carried out at Sheffield University at the moment. I think it would be advantageous for metallurgists both in France and the U.K. to compare notes on their researches, since evidence afforded by Professor Crussard's microfractography seems likely to supplement that obtained by more macroscopic methods.

I am sure that, if he were here, Professor Quarrell of Sheffield University would join with me in inviting Professor Crussard and his colleagues to visit us in the near future in connection with this most interesting and important subject.

CORRESPONDENCE

Monsieur **R. Borione** (IRSID) wrote: The methodical study of Messrs. Burns and Judge shows great concern to separate the respective influences determining the ferrite grain size and that of the pearlitic structure. It has shown that if in the range of pearlitic transformation (700–600° C) it is perhaps an advantage to cool the steel at a rate much greater than 70°C/min, then there is no point in exceeding this rate in the range of ferrite transformation (860–700° C).

The authors also give evidence of the influence of the cooling rate below 600° C, which they show to be weak or negligible. These findings agree with those of IRSID derived from experiments on a very mild steel.*

It is clear that the results of this study are only applicable to cooling rates corresponding to an annealing transformation. Perhaps the study of the influence of quenching of steel as it leaves the rolling mill, followed by tempering for fine sorbitic structure, should also be of interest for steels of the group studied, of which the carbon content is rather high.

Messrs. Burns and Judge express the opinion that the austenitic grain-size affects the transition temperature independently of the ferritic structure, apart from the indirect influence caused by its action on this structure. This agrees with the findings of IRSID in a study of hull plates for naval vessels (in collaboration with the Institut de Recherches de la Construction Navale). The findings were as follows. On 8 plates of mild steel, supplied from different sources but having the same ferrite grain size (nos. 7–8 ASTM), 7 plates had a McQuaid fine grain size (no. 7, 6, or 8), and only one had coarse grain size (McQuaid no. 1–2). For these plates we compared experimental values of the transition temperature (of ductility) with the value calculated from the C, Mn, Si, and P ratios following an empirical formula, which is generally satisfactory for this category of steels within the limits of composition adopted for the experiment. We showed a remarkable agreement between the calculated and measured values for 5 of the 7 plates with the fine McQuaid grain size (differences from 1° to 6°), when, for the plate with the coarse McQuaid grain size, the calculated transition temperature was 30° C lower than the transition temperature of the test. (The discrepancy found for two of the plates with the fine McQuaid grain size is explained by the presence in notable quantities of residual elements, Cr, Ni, etc., not involved in the formula.)

Finally, we wish to make two comments on the criteria of breakage chosen to define the transition.

We think in the first place that the determination of a conventional transition temperature corresponding to 5% of the grain size at the break (or, equally, at 40% of the grain as prescribed by the Lloyd's Register of Shipping) may be extremely inaccurate as it is established by means of a small number of test bars broken at each temperature. A statistical study made at IRSID on a normalized, very mild steel, by means of 100 specimens submitted to a Charpy **V**-notch test at the test temperature, showed indeed that the individual values of the proportion of grain in the cracks were widely scattered about the average figure except when this figure was very high; e.g. in a test of 100 specimens the range is of the order of 15% when the mean proportion of the grain in the crack exceeds 85%, but it is around 45% for the proportions below 60%.

Concerning the use of a criterion based on the fracture appearance to determine a transition-temperature related to the crack propagation, the writers believe that it is not very applicable to small notched bars of 10 × 10 mm. In these specimens indeed, the crack does not spread in the metal in this initial state, as in an actual plate, but in a metal which is physically altered by the plastic deformation which occurred during the period preceding fracture.

Monsieur **J. Plateau** (IRSID) wrote: In observing cracks which appear in a specimen during the deformation which precedes fracture it is important to determine the mechanism of this deformation. The existence of these ' non catastrophic cracks ' confirms the possibility of an internal initiation and shows that certain conditions must be fulfilled to permit propagation of the fracture. These conditions should be exactly determined. For this reason we would like to know if Messrs. Burns and Judge have been able to make some observations on (*a*) the length, direction, and position of the cracks, and (*b*) the heat-treatment and zone of test temperature which favours their formation.

* C. CRUSSARD et al.: *J. Iron Steel Inst.*, 1956, vol. 183, June, pp. 146–177, and *Rev. Mét.*, special no., June, 1956, pp. 140–174.

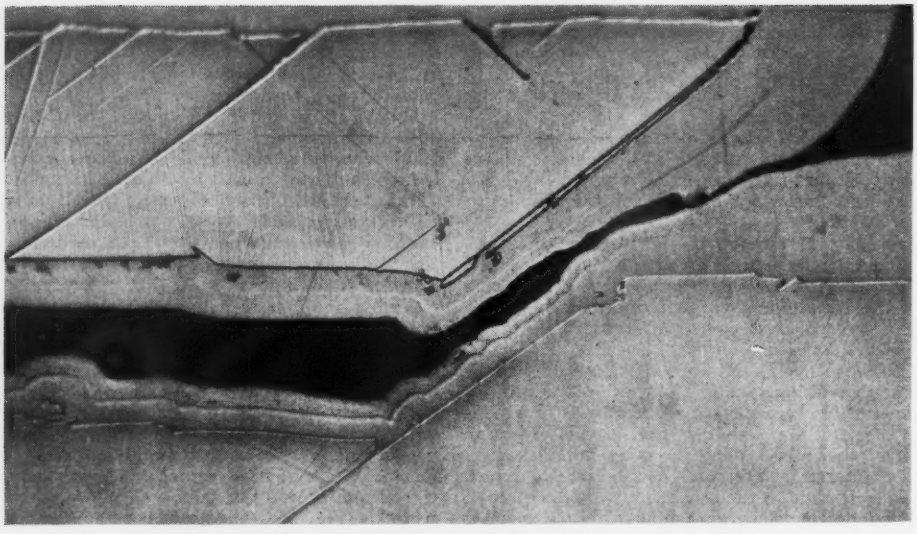


Fig. A—3·5% silicon–iron specimen, etched in 2½% nital × 500

Mr. **J. M. Berry** (G.E.C. Research Laboratory, New York, U.S.A.) wrote: Some observations made on the fracture surface of 3·5% silicon–iron crystals revealed a phenomenon which appears to be quite similar to the 'tongues' observed by Professor Crussard and his co-workers. These are believed to be characteristic of fracture on the interface between twinned and untwinned material.

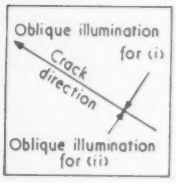
A single crystal of silicon–iron was notched in such a manner that cleavage on the (100) plane could be made to occur in the [110] direction. This crystal was fractured at − 196° C by means of a single sharp blow delivered to a wedge that had been inserted into the notch in the crystal. During the examination of the fracture surfaces under the microscope at 100 diameters using vertical illumination, rather wide dark bands parallel to the direction of fracture propagation [110] were noticed. When additional illumination was provided in the form of spotlights oblique to the fracture surface and at right-angles to the direction of crack propagation [110], the formerly dark bands were seen to be relatively smooth bright facets inclined to the fracture surface at about ± 35°. The two fracture surfaces appeared to match each other in every detail. These facets were believed to be associated with twinning since there is a set of twins in iron whose traces on the (100) plane are parallel to the [110] direction. Because of their appearance, the facets were at first believed to be cleavage planes (100) in the twinned material. But the only (100) type planes, having intercepts in the fracture surface parallel to the direction of crack propagation [110], are inclined to the fracture surface at about 70°. Since the twin boundary is inclined at about 35°, it was inferred from this observation that cleavage had occurred at the interface of the twin and the parent crystal.

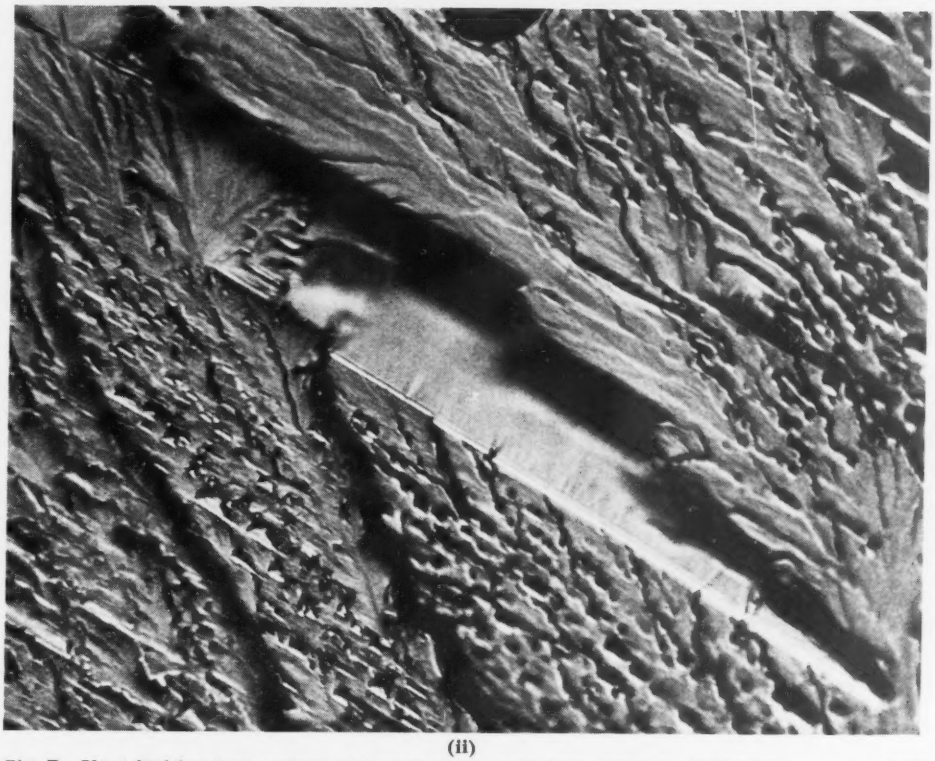
The specimen was plated to preserve the fracture surface and a cross-section was made so that the (110) plane (normal to the direction of crack propagation [110]) and, consequently the profile of the fracture surface, could be studied. This showed (Fig. *A*) that the specimen had parted chiefly on two planes: (i) the (100) type (main cleavage plane), and (ii) the (211) type planes—the twin-parent crystal interface at about ± 35° to the cleavage plane in the parent crystal. Examples of cleavage on the (100) type planes in the twinned regions are also believed to have been observed (i.e., at several locations across the twin attached to the flap in the upper part of Fig. *A*). The orientation is such that re-entrant angles are formed when cleavage occurs on this plane, and examples are rare and difficult to be certain of. Like the tongues observed by Crussard, these interfaces exhibit markings. If the fracture surface is tilted so that the interface can be illuminated vertically, the markings appear to be composed of the 'river patterns' and markings which exhibit definite crystallographic directions. These are believed to be tearing and cleavage across the twin which show up as differences in level under this type of examination. It is also possible that secondary twin traces are being observed.

The foregoing remarks pertain to observations made on the heavily twinned regions near the beginning of the fracture (near the base of the notch). In this region the crack was propagating on quite different levels simultaneously. The levels join eventually in large shear-type cleavage steps or in cleavage along the junctions of twins with the parent crystal. However, what was believed to be analogous behaviour was observed at great distances from the notch. In these regions, the 'river pattern' of cleavage steps joining relatively small differences in level is the predominating feature of fracture surfaces. Figures *B*(i) and *B*(ii) are photomicrographs at 2000 diameters of such a region of the fracture surface. The areas in these figures are the same but they were obliquely illuminated from opposite sides. These photomicrographs show that the 'river pattern' contains crystallographic facets. It should be noted that these facets also make traces in the (100) plane parallel to the direction of crack propagation [110]. This suggests that rivers and their tributaries are formed by (alternately) shearing and by cleaving on the twin-parent crystal interface.

In another crystal of silicon–iron so made that the direction of crack propagation was [100], bright facets at an angle to the cleavage surface were also observed. The traces of these facets were at 90° to each other, which is consistent with the expected angle between a set of twin traces in this orientation. Perhaps the tongues observed by Crussard could be explained in terms of very small twins produced in the fracture process.

(i)





(ii)

Fig. B—Unetched fracture surface, obliquely illuminated from opposite directions × 2000

AUTHORS' WRITTEN REPLIES

Mr. **G. Burns** and Mr. **C. Judge** (Royal Naval Scientific Service) wrote in reply:

We thank Messrs. Borione and Plateau for their comments, both of which raise interesting points.

It is gratifying to learn from Monsieur Borione that some of the conclusions we reached from a study of a single steel with a carbon content rather too high to be truly representative of the general run of mild steels, are in accord with the findings of IRSID on ranges of representative constructional steels.

Although, as Monsieur Borione points out, the steel chosen for our investigation could have been used to study the influence of treatments resulting in sorbitic microstructures, we deliberately restricted our heat treatments to those which would produce only pearlitic structures such as would occur in ordinary as-rolled, or normalized, mild steels.

We appreciate the point made by Monsieur Borione that determination of a transition temperature on the basis of fracture appearance at a small percentage of crystallinity, and using only a few test pieces at each testing temperature, may not always be reliable; but for the steel used in this investigation, which was chosen for its uniformity, the results were, at all times, very consistent, and we have confidence in their comparability among themselves. We agree that the transition temperatures we have determined are conventional, and do not necessarily correlate with behaviour which would be observed in large specimens.

We regret that we are not able to give a definite answer to Monsieur Plateau's two questions. The occurrence of the phenomenon of isolated cleavage cracks forming at an early stage of deformation, and not spreading, was sporadic with reference to both heat treatment and testing temperature. After it was decided to examine the phenomenon of audible clicking, several attempts were made to produce additional examples by duplicating tests in which clicking had been observed initially; none of these attempts was successful, and we are unable to define with certainty any conditions which lead to the occurrence of this phenomenon.

Professor **C. Crussard** and his co-authors (IRSID) wrote: Mr. Berry's very interesting observations are in good agreement with the results obtained by micro-fractography;† there is no doubt that the cleavage facets visible in the silicon–iron shown in Fig. 3 are similar to the tongues we found in mild steel (*see* Fig. 17 of paper and Fig. *A*). By comparing the shadow replicas of these tongues with those of spherical latex particles, we have shown that they make an angle of 30–35° with the cleavage plane; this confirms Mr. Berry's hypothesis that they would be parallel to the (211) plane.

We have observed the same tongues in brittle fracture of mild steel at testing temperatures between − 20° and − 196° C, in fractures of 4% silicon–iron and in a bainitic 0·35% C, 1% Cr steel; on the other hand, we have not found them in zinc. Finally, tongues are not found in the fracture of mild steel if this is preceded by heavy cold work.

This set of experimental data, including those provided by Mr. Berry, does not appear to permit us to decide between two possible hypotheses to explain the formation of tongues.

The first is that suggested by Mr. Berry, by which the tongues correspond to cracks following the interface between a twin and the parent crystal, small twins being formed during the propagation of the crack. It should be noted in this connection that the analogy suggested by Mr. Berry between the tongues and the coarser structures observed at the base of the notch (Fig. 1) is not quite perfect, as Fig. *B* shows. In the former case, the crack follows the same cleavage plane all round the tongue; in the latter, fracture proceeds along different parallel planes, since the crack follows the twin/crystal interface.

The second explanation is that the tongues correspond to small cracks following the slip planes, caused by the piling-up of screw dislocations.

The (211) slip plane being the same as the twin plane, it is impossible, so far as mild steel is concerned, to reject either of these hypotheses. However, it may be that in silicon–iron the (211) plane is not an active slip plane, which would support the validity of the first explanation. For that reason we should like to know whether Mr. Berry was able to observe if, under conditions similar to those he used for fracturing the silicon–iron monocrystal, there was any slip along the (211) plane.

† J. Plateau, G. Henry, and C. Crussard, *Rev. Univ. Mines*, 1956, vol. 12, pp. 543–554.

THE ELECTRON PROBE MICROANALYSER

This discussion was based on the paper by J. Philibert and C. Crussard, entitled "**Application of the Electron Probe Analyser**" which appeared in the May, 1956 issue of the *Journal* (vol. 183, pp. 42–47).

Prof. **C. Crussard** (IRSID) presented his paper.

Sir **Charles Goodeve** (B.I.S.R.A.): I congratulate the authors on the exciting work they have carried out in such an efficient way. This instrument gives the metallurgist and chemist a valuable new road to a knowledge of structure. At this stage it naturally has some limitations, one of which is its inability to analyse for elements lighter than chlorine. I am glad to hear that it is intended soon to push this down to magnesium. Some work is now going on at A.E.I. laboratories in the U.K. in collaboration with four of the metallurgical research associations to develop an instrument to go down as far as carbon. Could Professor Crussard comment on the commercial future of the instrument in France and also give some indication of the speed of operation?

Professor **Crussard**: I am very grateful to Sir Charles Goodeve for having told us about these new developments.

I also understand that Dr. V. E. Cosslett is attempting to develop scanning techniques which will produce a chart showing the distribution of the alloying elements on a metallic surface.

In reply to Sir Charles Goodeve's questions the speed of operation depends on the accuracy required. For a highly accurate result, a reading time of about 1 min is required.

A French company has undertaken to produce the instrument commercially without any changes from the prototype.

Dr. **H. H. Burton** (English Steel Corporation Ltd.): On p. 45 of the paper the authors state that when

applying their method to Ni–Cr–Co austenitic steel they found that the carbides contained only niobium. I would be interested to learn if they have yet applied the method to a segregate from a large ingot containing chromium–molybdenum or nickel–chromium–molybdenum. By much coarser methods we find there is a very large amount of segregation of molybdenum.

Professor **Crussard:** I mentioned only manganese in the paper since it is the element which we found to have the largest segregation. We are, however, very interested in the segregation of nickel and chromium. I think that K. J. Wolfe and I. R. Robinson have shown by microradiography that molybdenum has a direct effect on this segregation of manganese but we have not yet started an investigation of this.

Madame **A. R. Weill**: I wish to refer to the discontinuity in the copper–antimony alloys. A few days ago I learnt that diffusion in copper–antimony alloys is being studied at Princeton and a discontinuity in the diffusion coefficients of antimony in copper has been found. This phenomenon is extremely odd and does not seem to obey any known law. I believe that the figures obtained are within the range of the percentages quoted by Professor Crussard.

Professor **Crussard:** Our work concerns the simultaneous diffusion of copper and antimony in iron; the antimony precedes the copper.

Madame **Weill:** There is possibly a copper–antimony alloy in which the elements inter-react. Professor Crussard's problem is obviously not a simple one. His approach to it is very interesting.

Professor **Crussard:** I wish to mention that the study of diffusion in copper alloys has been made by a young Yugoslav engineer from the Institute Metallurgique de Ljubljana, Monsieur Sirca, who is making a complete study of these problems using also micro-radiographic and auto-radiographic methods. He will publish his results shortly.

SYMPOSIUM ON SINTERING

In November, 1953, an International Symposium on Sintering was organized by The Iron and Steel Institute. Other meetings had been organized before and after this Symposium in a number of countries to study the sintering process. However, the symposium in London enabled a wider exchange of ideas on this subject.

It has become apparent that owing to the development of sintering throughout the world and because of the numerous studies which have been carried on during the last three years, a second Symposium should be organized on an international scale to permit discussion of these further advances. IRSID have therefore decided to organize such a Conference in Paris in May, 1957. The programme will be as follows:

Tuesday, 21st May—The Mechanism of Sintering

1. Broad aspects of the theory of Sintering (permeability, fuel combustion, waste-gas composition, transfer of heat, etc.)
2. Desulphurization and general problems; elimination of various impurities.
3. Sinter quality and the means of studying its composition. Degree of oxidation, porosity, size analysis, mechanical methods.

Wednesday, 22nd May—Process of Sintering Iron Ores

This session will be devoted to industrial aspects of sinter and, in particular, to the use of the Dwight-Lloyd machine. Some papers on other processes (pelletizing, etc.) will, it is hoped, also be presented.

1. General review of the state of development of sintering in the world and future advances.
2. A discussion on the use of different solid fuels.
3. A discussion on the use of extended ignition and the preheating of air.
4. A discussion on the preparation of materials, granulating, etc.

Thursday, 23rd May—The Use of Sinter in the Blast-furnace

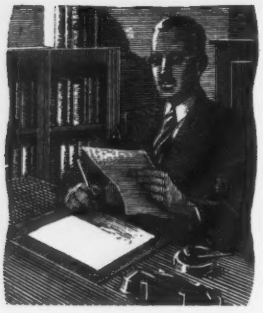
Papers describing blast-furnace operation with various percentages of sinter contributed by various countries, notably from the U.K.

Application forms can be obtained from

Monsieur M. Allard,
Directeur-Général de l'IRSID,
185 Rue Président Roosevelt,
St. Germain-en-Laye (S. & O.), France.

With these application forms will be provided a list of hotels in Paris with approximate indications of their price. It is expected that the delegates to the Symposium will make their own reservations, and they are advised to make early application. The meeting will be held at the Salles de la Maison de la Chimie, 28 Rue St. Dominique, Paris 7. It is intended that the verbal proceedings will be simultaneously translated into French, English, and German.

A contribution to the expenses will be requested from each delegate. This will enable them to receive before the Symposium copies of the papers which will be preprinted in their original language and accompanied by a one-page summary in French, English, and German.



CORRESPONDENCE

Correspondence on Papers · Letters to the Editor

Correspondence on the Paper—

Corrosion Resistance of Some Austenitic Cr–Ni Steels of 18/8/Ti Composition*

By E. J. Heeley and A. T. Little

Dr. **E. Houdremont** (Essen-Bredeney, Germany) wrote: The work described in the paper confirms the view that with a carbon content below 0·1%, a Ti : C ratio of more than 4 : 1 is enough to prevent intercrystalline corrosion after a critical anneal in the range 600–750° C, if it is considered that enough titanium will be present to bind all the nitrogen, and possibly also the sulphur and the oxygen. The authors in particular confirm the advantage of a stabililizing treatment at 880° C, in drawing attention to the fact that at this temperature the carbon is combined in a harmless state as TiC (cp. the work of Bungardt and Lennartz†).

After the softening treatment (quenching from temperatures above 1050° C), there will always be some carbon in solution which will precipitate in the critical range preferentially as chromium carbide at the grain boundaries. Conversion to TiC and coagulation only occurs as a result of a stabilizing treatment.

The corrosion cracking resulting from heating in the temperature range where melting begins (1300° C and above) is due to the fact that as the melting point is approached, the grain boundaries enriched in carbon and other impurities will melt first, because there a carbon-depleted matrix is in equilibrium with a melt with a higher carbon content. This leads to further enrichment of the grain boundaries in carbon and other impurities. In these enriched zones, precipitation will also occur at high cooling rates, as has been shown on ferritic stainless steels containing 18% Cr. For these ferritic steels a longer annealing treatment at 750° C is sufficient to remove these precipitates or to coagulate them, but for the austenitic steels a longer anneal at higher temperatures is necessary, because of the slower diffusion rate in the face-centred cubic lattice. But if the annealing temperature is too high (i.e. above 1050° C), the TiC is taken into solution again, and so the danger of corrosion attack remains. Moreover, the segregations resulting from incipient melting increase, if δ-ferrite is produced by these segregations. The authors do not consider whether any δ-ferrite exists in their alloys at 1300° C, as might be expected from the constitution diagram. If some δ-ferrite is formed at high temperatures, this can transform to sigma to a greater or lesser extent. Other investigations of austenitic steels have shown that the nickel, manganese, and chromium segregations produced at the start of melting or by the equilibrium between δ-ferrite and austenite at about 1300° C do not disappear until a temperature of 1050° C is reached. It therefore seems that sensitivity to cracking at 1300° C can only be reduced by annealing in this temperature range.

It is also clear that the conception of incipient melting at the grain boundaries means that the segregation of carbon and other impurities will be reduced with decreasing carbon content.

AUTHORS' REPLY

Mr. **E. J. Heeley** and Mr. **A. T. Little** (Imperial Chemical Industries Ltd.) wrote: We have studied with great interest Dr. Houdremont's suggestion that incipient melting at grain boundaries contributes to the 'high-temperature' (1300° C) impairment of corrosion resistance which occurs in some 18/8/Ti steels.

Whilst there is no doubt that, in the course of a welding operation, incipient melting of the parent material does occur in a very narrow zone immediately adjacent to the deposited weld metal, and also that the extent of this zone will depend on the overall chemical composition of the steel, microscopical examination of heat-treated plate material has so far not indicated that any melting takes place when 18/8/Ti steels of the compositions covered by our work are heated to a temperature of 1300° C, although this heat-treatment results in considerable impairment of corrosion resistance of certain of these steels. Incipient melting therefore does not appear to be necessary for the development of susceptibility to the '1300° C' effect in the 18/8/Ti steels under review.

In this connection it is interesting to note that in the case of certain niobium-bearing 18/8/Nb austenitic Cr–Ni steels, although heating to temperatures of about 1340° C causes partial fusion, these steels are very much less susceptible to the '1300° C' effect than are the 18/8/Ti steels.

With regard to Dr. Houdremont's remarks on the occurrence of δ-ferrite, this constituent is present in varying amounts in several of the 18/8/Ti steels which had been heat-treated at 1300° C, but in no case was there any evidence of the presence of sigma. The latter may, of course, be developed on further heating these steels at 880° C, and it is possible that the behaviour of the 0·1% C 18/8/Ti steels after receiving a double heat-treatment at 1300° and 880° C, as described in the paper, is in part influenced by the formation of small amounts of sigma.

* *J. Iron Steel Inst.*, 1956, vol. 182, March, pp. 241–255.

† K. Bungardt and G. Lennartz, *Arch. Eisenhüttenwesen*,. 1956, vol. 57, pp. 127–133.

Correspondence on the Paper—

Thirteenth Century Smelting Residues from Kirkstall Abbey*

By R. Haynes

Mr. **J. Piaskowski** (Cracow) wrote: The paper by Dr. Haynes describes a type of investigation which is of great importance for the understanding of ancient metallurgy. However, some of his conclusions require some explanation.

I am doubtful whether his "bright-green lumps of earthy material" with embedded charcoal are in fact a slag produced during the smelting of bronze from copper and tin ores. This method was unknown; for many centuries bronze was made by alloying metallic copper and tin, and the monk Theophilus (11th–12th century) described only the latter method. It is possible that this material was not a partially smelted charge, but was rather a slag resulting from bronze melting in the foundry. This hypothesis is confirmed by the very low sulphur content (0·10%) in the slag and by the presence of bronze foil. The use of bronze foil in a smelting furnace is difficult to explain, but, however, it is understandable in a foundry charge.

Dr. Haynes also mentioned the examination of a "dark, porous, cindery mass", and described it as a slag from iron smelting. However, this material has a very low iron content (5·78% FeO). Slags from medieval bloomeries usually contain about 40% FeO and 10% Fe_2O_3, and so this material is unlikely to be slag from iron smelting. Agricola stated that in lead smelting an iron powder was added to the refractory clay; it is also possible that the clay itself might contain some iron oxide. It seems probable that the "dark, porous cindery mass," described by Dr. Haynes was the lining of the crucible or foundry furnace.

There must have been a bronze foundry at Kirkstall Abbey. It is well known that such workshops were often found in medieval monasteries. This suggestion has additional support. I have examined very similar materials derived from a 16th century foundry excavated in Cracow, consisting of:

(*a*) Bright-green slag with embedded wood charcoal.
(*b*) A dark, porous, earthy mass, containing iron.
(*c*) Residues of clay moulds, crucibles, wood charcoal, and bronze castings.

Up to the present only the metal and the moulding materials have been examined; the slag will be analysed in the near future.

AUTHOR'S REPLY

Dr. **R. Haynes** (Imperial Chemical Industries Ltd.) wrote: Mr. Piaskowski's remarks about the residues are interesting. The copper–tin residue I believe to be partially smelted charge, not slag. Support for this is given by the fact that I was easily able to smelt a little of the residue to bronze in a very simple shaft furnace. Additionally, the metallic particles embedded in the residue were very variable in composition (16–30% tin) and I would not expect the compositions of particles obtained from a slag produced in a melting operation to vary as widely as this. An explanation for the presence of a little bronze foil is not difficult to find, for the addition of scrap metal to a smelting charge must have been an obvious way of reclaiming the metal. I do not regard the low sulphur content of the residue as being indicative of a melting slag, since many oxidized copper ores are remarkably free from sulphur. Undoubtedly bronze has been produced by smelting tin and copper ores together† from the earliest times, and preparation of bronze by melting copper and tin together does not preclude the use of the earlier method elsewhere.

A subsequent dig brought to light a 15th century hearth with the remains of a crucible resting upon it.‡ This crucible contained fragments of bronze, of various compositions, awaiting melting. Bronze objects also have been found frequently.‡ These finds provide ample evidence of bronze founding at the Abbey, but again do not preclude the smelting for bronze in the earlier period, soon after the foundation of the Abbey.

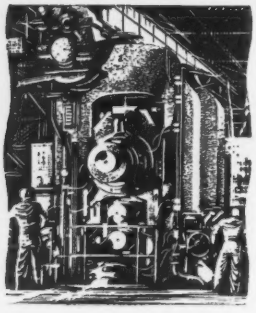
The suggestion that the iron residue may be part of the lining of a crucible or foundry furnace is plausible, and overcomes the difficulty presented by the low iron content of the material. However, the residue was different from the material of the 15th century crucible. Iron founding at Kirkstall Abbey is well attested both by documentary evidence and by other finds of considerable quantities of iron slag and charcoal. (Some of this slag had a total iron content of about 50%, which was present in roughly equal proportions as ferrous and ferric oxides§). Indeed, it is interesting to note that the present-day Kirkstall Forge, which stands adjacent to the Abbey precinct, traces the forging of iron at Kirkstall back to the Abbey.‡

* *J. Iron Steel Inst.*, 1956, vol. 183, Aug., pp. 359–361

† R. J. Forbes, "Metallurgy in Antiquity", p. 256: 1950, Leiden, E. J. Brill.

‡ D. E. Owen, "Kirkstall Abbey": 1955, Leeds, E. J. Arnold & Son, Ltd.

§ E. Simister, "Kirkstall Abbey Excavation: Fourth Report": Publications of the Thoresby Society, 1953.



IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group

IRON AND STEEL ENGINEERS GROUP

REPORT OF THE THIRTY-FIRST MEETING

THE THIRTY-FIRST MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held in South Wales on Thursday and Friday, 4th and 5th October, 1956. The technical sessions were held in the Grand Pavilion, Porthcawl, with Mr. W. M. LARKE, Chairman of the Group, in the Chair.

At the second technical session, on Friday, a paper on "Planning the Conversion of a High-lift Slabbing Mill to a Universal Mill" was presented by Mr. C. E. H. Morris and Mr. R. N. Dale, Steel Company of Wales, Ltd., and was discussed. The paper is given below; the discussion will be published in the May issue.

Planning the Conversion of a High-lift Slabbing Mill to a Universal Mill

By C. E. H. Morris and R. N. Dale

SYNOPSIS

In 1958 the Steel Company of Wales Ltd. will replace their existing 45 in. × 115 in. high-lift slabbing mill with a universal slabbing mill. This paper outlines the engineering design of the new mill, which will be required to roll an average of 60,000 ingot tons per week. In addition to the new 4000-h.p. drive for the vertical rolls, modifications will be made to the mill tables and manipulators.

The preliminary planning is already in hand for completing the conversion in as short a time as possible. A high degree of organization and control is required to co-ordinate the electrical and mechanical work involved. 1373

FOR SOME YEARS the Steel Company of Wales have been investigating the capacity of their 45-in. high-lift slabbing mill (Fig. 1). This has involved many detailed observations by the rolling mill management and the operational research department and has included the use of new methods and techniques being developed by the Company and B.I.S.R.A. The reason for this investigation was to determine by what methods rolling techniques and rates could be improved, and to analyse the various factors involved in slabbing mill operation. The need for this was accentuated by the fact that this primary mill has to absorb the full make of the Company's open-hearth shops and roll slabs for the 80-in. strip mill of widths ranging from 27 to 72 in. and thicknesses from 4 to 8½ in. It was, therefore, of great importance in considering future extensions of iron- and steel-making capacity to know with reasonable accuracy at what point the existing mill

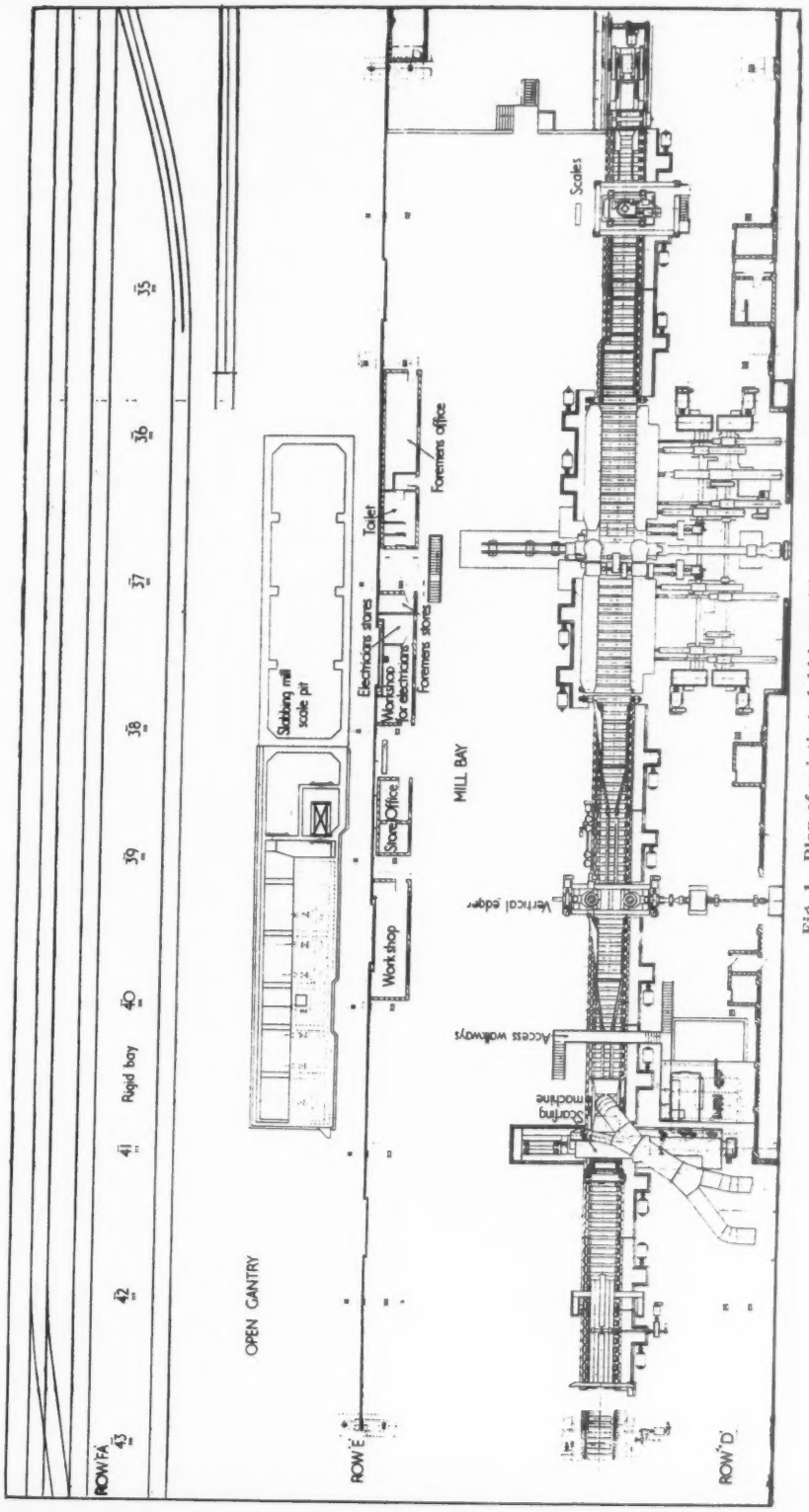


Fig. 1—Plan of existing slabbing mill

would reach saturation. Operational times were carefully studied and items such as screwdown speeds, mill-roll speeds, the proportion of the time the slab is out of the rolls, etc., were all thoroughly investigated. Two important factors in a mill for these duties are the rate at which ingots can be fed to it from a growing soaking pit installation, and the time taken in manipulating ingots, and later slabs, for edging and flat passes.

The development schemes in hand at the end of 1955 were designed to give a steelmaking capacity of 48,000 ingot-tons/wk in the first quarter of 1957. Since then it has been decided to extend this to 60,000 tons/wk in the first quarter of 1959. The additional tonnage will be produced in a Bessemer shop operating on the steam–oxygen process.

The results of the mill investigations revealed that, for the anticipated orders, the existing mill could process 60,000 tons in a rolling time of 132 h. This, however, did not include any allowance for delays due to heat stops, maintenance periods, minor breakdowns, and all other interruptions to production. This high rate of rolling would also seriously affect the quality of the slabs, since it could only be achieved by a reduction in the number of passes. Furthermore, to average 60,000 tons/wk, the mill must have a capacity to absorb 65–70,000 tons in some weeks. It was therefore decided to replace the existing mill with a universal mill.

Ingots are fed to the mill by an electric-motor-driven buggy incorporating a tilting cradle. It reaches a maximum speed of about 900 ft per min and the length of track for the full soaking pit installation extends about 1000 ft. From the analyses of the mill operation, it was shown that to feed 60,000 tons of ingots singly would take 166 h. This is therefore an unsatisfactory method of transporting high tonnages, and under present conditions limits the mill output to 48–50,000 tons/wk. Various alterations have been considered, using trailer cars on the buggy, extending the ingot receiving table to shorten the buggy travel, etc. Unfortunately, there is not sufficient room to run a second track and use two buggies. The solution finally adopted was to use the buggy only as a receiving and tilting device, and incorporate a separate rope-driven shuttle car to carry the ingots to the mill. This was further developed by extending the buggy to take two ingots and increasing the length of the shuttle car. At any given moment, there are 8 ingots out of the soaking pits: two in the mill, two waiting, two on the shuttle car, and two being withdrawn from the pits and tilted on the buggy. By this means the mill can be fed at a rate of about 2 ingots every $2\frac{1}{2}$ min.

PRELIMINARY MILL DESIGN PROBLEMS

In the conception of this development scheme three main items were studied. These were:

i. The mill must be designed for the processing of 60,000 tons/wk of ingots.
ii. The mill must be easily installed in the mill buildings, making the most efficient use of existing drives, roller-table gear, and foundations.
iii. The existing mill must be dismantled and the new mill erected and commissioned in a sufficiently short time to avoid a major shutdown of the remainder of the plant.

It is intended to carry out the conversion in the summer of 1958, and during this period the rest of the plant will continue to operate at a reduced output. The timing of the installation of additional soaking-pit capacity will be arranged to enable the stock of ingots which will accumulate to be reduced to a normal working level before the Bessemer plant starts production in the first quarter of 1959.

GENERAL DESIGN DETAILS

Mill Horsepower

One of the methods by which high rolling rates are maintained is by tandem rolling. This reduces the time from ingot to slab, compared with single-ingot rolling, by between 30% and 45% for certain orders. The lower figure occurs when a pair of ingots can only be rolled head to tail for some three-quarters of the reduction, and have to be finished singly. This limitation is due to the distance between the mill and the ingot turnround, and to the length of the manipulators for tilting two ingots or slabs together.

In addition, over one-third of the 60,000 tons/wk will be ingots for tinplate orders. The hot-strip mill supplies the tinplate plants with coils in weights of 15,000 lb and 30,000 lb. To obtain higher rolling rates and efficiency the slabs are produced from 15-ton ingots, and it is inherent in the design of such ingots that there must be a considerable amount of edge reduction in the slabbing mill. This, in fact, is between 14 and 22 in., and in turn limits the extent to which full tandem rolling can be adopted because of the operative length of the manipulator finger-tilt.

On the consideration of these and other factors, an estimate has been made of the comparison between the outputs from a universal mill and the high-lift mill. For comparable orders the total rolling time for 60,000 tons/wk is 15% less for a universal mill than for the present mill, which in the main is due to the saving in manipulation time. To take full advantage of this saving it is essential that the horsepower driving the mill shall be sufficient to effect all the reductions, with a comparable saving in the number of passes. The two main mill motors on the horizontal rolls develop 4500 h.p. each and, by comparison with these, the latest universal and high-lift mills in production in the U.S.A. are driven by twin 6000 h.p. motors. To ensure that the mill as a unit will be sufficiently powerful, the horsepower for the vertical roll drive was ultimately fixed at 4000 h.p.

Mill Speed

The next problem to the motor horsepower was the determination of optimum mill speed. The horizontal rolls are nominally 45 in. diameter and the motor speeds range from a base of 40 rev/min up to 80 rev/min. When the mill came into production in November 1950, 40 rev/min was selected as the operating speed. During the past two years this has been varied for experimental purposes, and the tests have undoubtedly proved that rolling rates are increased at higher speeds, but with a rise in mechanical

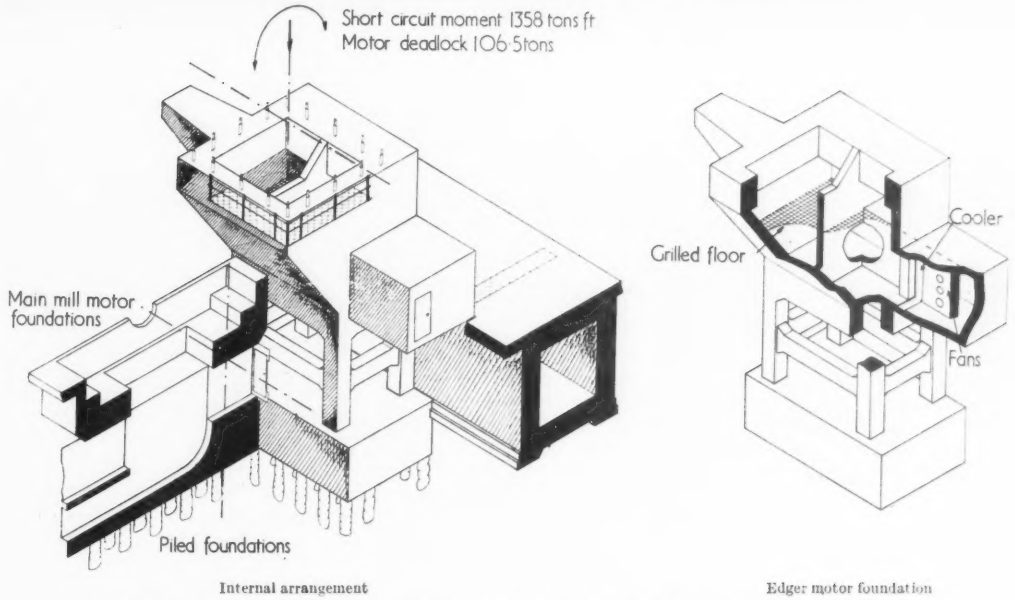


Fig. 2—Edger motor foundations (***Note:*** **"Motor deadlock" should read "Motor dead load")**

maintenance on breast rollers, entry tables and manipulators, the net gain is somewhat problematical. In addition, at higher speeds the ingots are thrown further out from the mill rolls. For a high-lift mill this extra 'time out of rolls' does not reduce the total rolling rate appreciably, because of other components such as reversal time and screw adjustment time. It will, however, affect the rolling rates on a universal mill where the piece has further to travel in one direction before being clear of the rolls. For these reasons the base speed of the vertical roll motor was selected at 75 rev/min, which corresponds to the base speed of 40 rev/min for the main mill rolls.

In normal operation in a universal mill the vertical rolls are used to hold the spread after the majority of the width reduction has taken place, during the first few passes with the ingot on edge in the horizontal mill. However, further edge reduction will be carried out during the flat passes and the design will permit up to ½ in. per side pass. This will be unidirectional into the mill, and the width will only be maintained during the reverse pass. Speed matching between the vertical and horizontal rolls will be preset by the operator for roll-diameter compensation. For the compensation due to the varying drafting in the mills, the vertical roll speed will drop as far as the limit of the current rise in the motor. The control scheme will permit this speed drop to be varied by up to 25% by alterations to the current limit.

Electric Drives

The motor will be a 1000-V single-armature d.c. machine, with an r.m.s. torque of 38·2 metre-tons. At nominal working peak the torque is 2½ times r.m.s. and 3 times at cut-out. The reversal time from base speed to base speed will be about 1¼ sec.

The supply will be obtained from an M.G. set driven by a synchronous motor of 4750 h.p., 500 rev/min, and 11 kV, designed to give a leading power factor of 0·8 at full load. The starting torque is 20% full load and the overload capacity 25% over for 2 h. Normal starting will be by means of a reactor with a limit of twice full-load current. There will, however, be provision for direct online starting with 3½ times full-load current.

The generators, in series, will be 1600 kW, 500V with an r.m.s. rating of 3200A, and will be as far as possible duplicates of the horizontal-mill motor exciting generators, but fitted with laminated frames.

As already mentioned, the speeds of the mills are matched and this is effected by connecting the edger-motor field with those of the horizontal mill motors. Automatic voltage control ensures constant voltage and an automatic current control reduces the voltage when current exceeds nominal working peak. These current limit circuits include magnetic amplifiers.

The armatures are also connected in series to give inherent load sharing without cross-compounding control. This will also permit rolling at half speed in the event of a breakdown of one generator. There will be 100% standby for the main and control exciter sets, selection of which can be determined through a link panel.

The design of the edger motor base is not yet final but it will be of reinforced concrete, generally as shown in Fig. 2. The piled foundation will be laid in the basement and by using prefabricated steel shuttering it is hoped that the pouring of the motor base can be accomplished quickly and without undue mess. The base structure fits snugly between the concrete work for the horizontal mill motors and the existing motor-room foundations and floor, and so it will be necessary to fit vibration dampers between them.

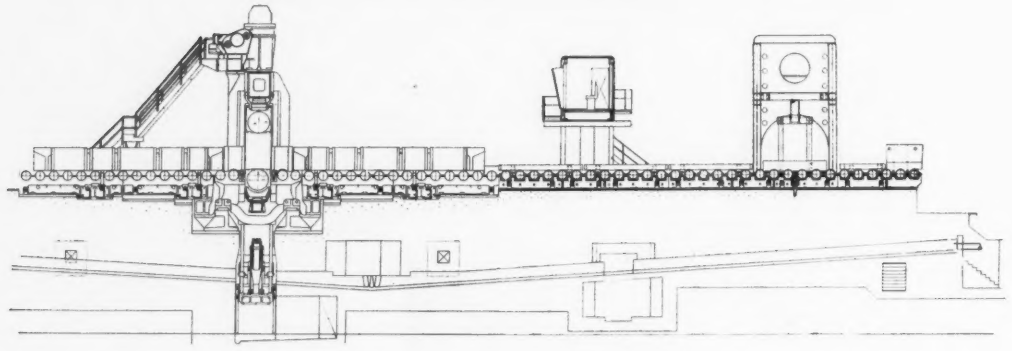


Fig. 3—Elevation of existing slabbing mill

The motor ventilation will be on the closed-circuit system and the fan room and ducting will be incorporated in the base. The requirements are 35,000 ft³/min at 2½ in. w.g.

Auxiliary drives for the manipulator finger-lift, feed rollers, and screw adjustment will all be on a Ward–Leonard system. In addition to providing good control this will also enable any future developments towards the fully automatic mill to be adopted.

Roller Tables

Many problems have been encountered during the past few years on the roller gear and drives on the entry and delivery tables of the existing mill. These have included bearing failures on the light and drive ends of the rollers (mainly attributable to cartridge bolt troubles), line-shaft fractures and bevel-gear wear. The most significant have been the fractures that have occurred in the main table-frame castings. These problems have all been met and, as far as possible, corrected. Immediately adjacent to and on each side of the mill are a pair of feed rollers which are driven, in pairs, through a gearbox. Owing to differences in pass-line and roll diameters, this gearbox has taken heavy loads with several failures and a scheme has been in hand for some time to replace this drive with individual slow-speed 35-h.p. motors.

The general design of the roller-table gear now became closely related to the universal mill design. At the beginning it was thought possible that a vertical mill assembly could be attached to the existing mill. This was soon found to be impracticable because to be compact and robust a universal stand should be considered as one unit with the vertical rolls as close as possible to the horizontal rolls. Even so, it has not been possible to produce as snug a layout as would be preferred; in some mills they are as close as 7ft 6 in. centres. In this case, there are limitations due to the arrangement of existing holding-down bolts, roller-table gear, and table frames which are also integral with the manipulator slide beams. It is necessary to arrange the feed rollers in relation to the vertical and horizontal rolls so that any length of ingot can be fed in, with or without any reduction being made in the vertical mill. The greatest span will be across this mill and it was felt that this should be not more than 5 ft. As a result it was necessary to adopt mill centres at 9 ft with two individually driven rollers between them and two more on the entry side. Figure 3 shows a section of the existing tables, and the new mill and the feed rollers will occupy the space of 4 existing table rollers. The whole of the first table section of 7 rollers will therefore be removed and replaced with one of 3 rollers only. It is of interest to note that the difference between 7 ft 6 in. and 9 ft in these mill centres results in a total effective loss of 3 h rolling time per week due to the greater time between passes.

With the intention of carrying out a quick change-over, it had been hoped that the new main mill housings would rest on the existing sole plates, and that an additional sole plate could easily be installed for the vertical mill. This is not possible, however, partly owing to the roller-table foundations and partly because the existing sole plates have settled nearly ¼ in. in the last 6 years. It would be unsatisfactory first to assemble a new mill in the manufacturer's shops and then instal it on site on two separate sole plates, one old and one new. When the conversion is being carried out, therefore, the existing sole plates will be removed and new ones placed in position, using existing bolts. The two plates will weigh 130 tons and 60 tons.

Manipulators

The existing manipulators are similar to those which the United Engineering and Foundry Company have installed on several mills produced since the war. It is basically a sound design but has during the last five years shown certain weaknesses and has been superseded by a new design by U.E.F. Co. There are four lifting dogs suspended on crank arms mounted on a common shaft (Fig. 4). On a central crank arm is connected a long rack beam. This rack is driven from a train of gears mounted on the main drive shaft for the manipulator head. In normal operation, the rack is driven forwards and backwards at the same speed as the manipulator head. To the casing of the rack drive gearbox is attached a connecting rod whose other end is attached to a crank on the output shaft of a reduction box. A 150-h.p. motor drives this

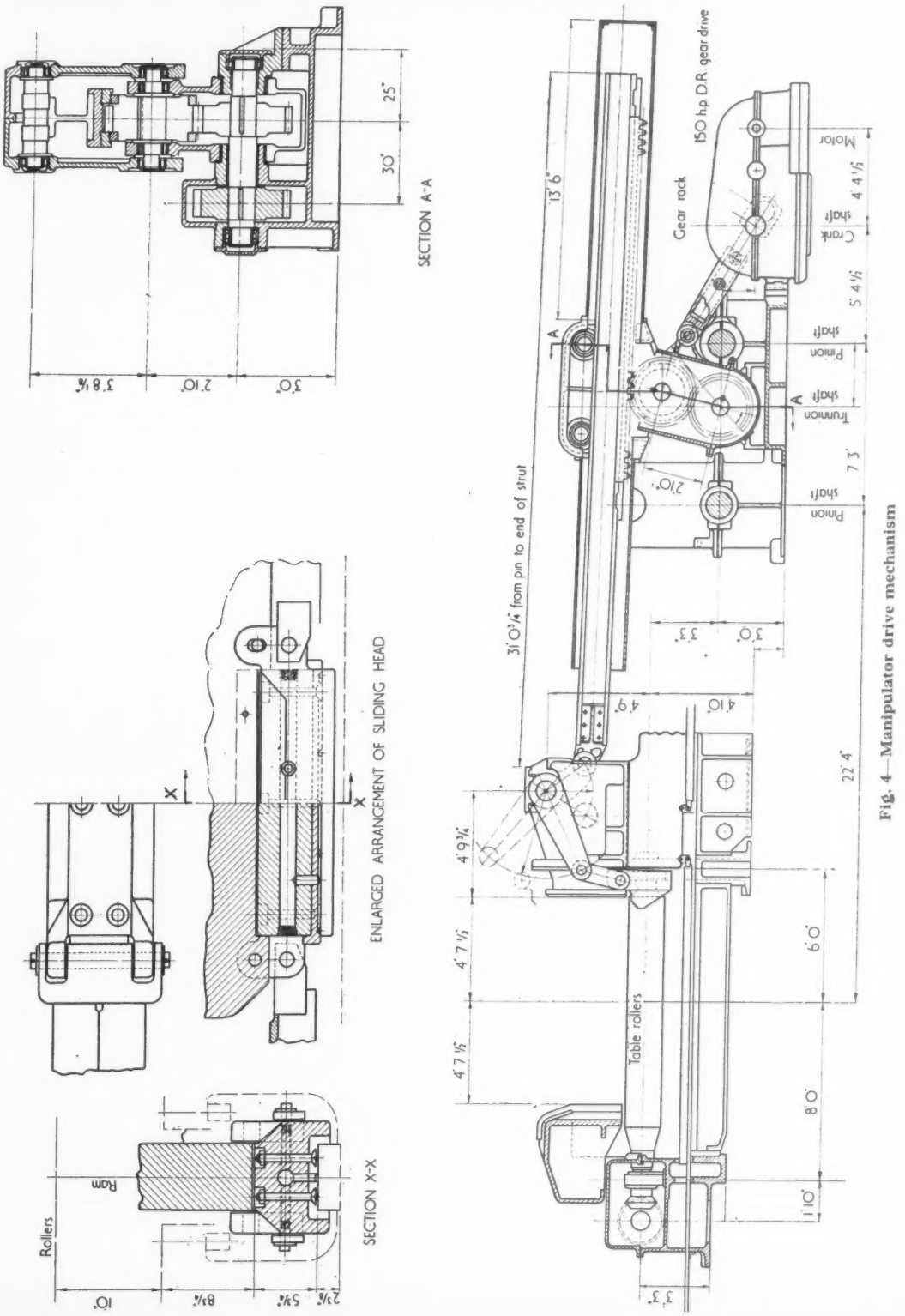


Fig. 4—Manipulator drive mechanism

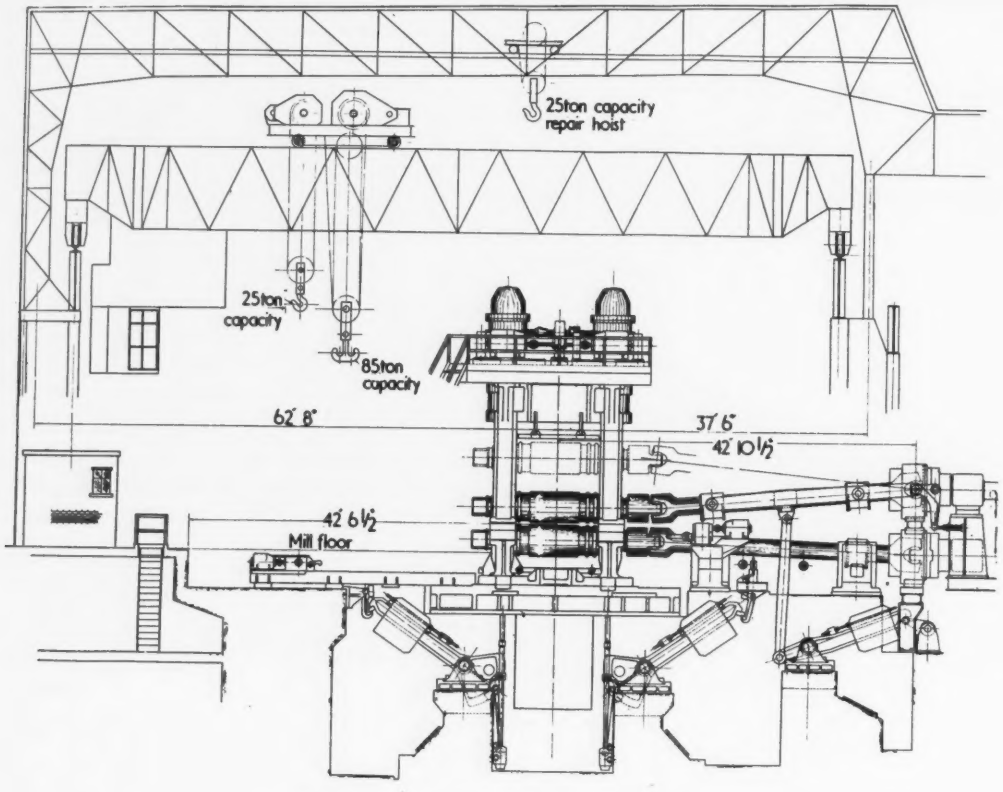


Fig. 5—Cross-section of mill building

crank and for tilting operation this motor is energized and the connecting rod pushes the rack drive box forward in an epicyclic motion. This moves the rack beam relative to the manipulator head and the lifting dogs move up and down through their complete stroke. The motor only completes 9 revolutions during the full cycle and the original electrical control scheme was not fully suitable for this duty. In the change of design outlined later it will be replaced by an improved variable-voltage scheme.

In this generally robust design the weak point is in the connecting rod itself. This is in two sections held together by two 2-in. dia. shear pins, and it is extremely difficult to maintain such a shear pin unit so that it will fail at the designed load, which in this case is 80 tons. If they do not shear, severe loads are incurred in the drive gears. If they shear repeatedly the fit is very quickly affected and they cease to function correctly. The manipulation of ingots in tandem increases the load on the drive but does not exceed the designed figures. The rigidity of the drive, however, does render it liable to shearing loads being developed not on the up-stroke but on the down-stroke should the dogs come down on top of the slab or on a lump of scrap on the tables.

Further troubles occur in the sliding members. Each manipulator head sits on two shoes which slide on two beams running across the roller table frames. The difficulties of keeping these shoes adequately lubricated and the slides free from scale are well known to any steelworks engineer.

To install the vertical roll unit on the entry to the mill, the last 4 ft of the entry manipulators have to be removed. In addition, the two main slide beams nearest to the mill would foul the vertical roll assembly. A new design has therefore been incorporated in which the support beams lie outside the table frames. On these are fixed inverted shoes in which the manipulator head slides. This keeps the slides much freer from mill scale and should be a considerable improvement.

With the reduction in length of the manipulator, it is still necessary to be able to tilt two ingots together, and the present finger-tilt centres of 4 ft 10 in., 7 ft 3 in., and 4 ft 10 in. are being maintained but moved proportionately further from the centre-line of the horizontal mill.

By this time, it was apparent that the existing manipulator drive and finger-tilt mechanism could not be fully adapted to the new installation. Accordingly, a large section of the drive will be removed and replaced with new units. The finger-tilt drive will be mounted on the manipulator head as is common on many designs. It will be powered by two 100-h.p. motors with a slotted link operating the main cross shaft. It should be borne in mind that the amount

of tilting required for the universal mill will be about one-third of that in present operations.

The whole drive is being so designed that as many existing holding-down bolts as possible will be re-used. There are a few extra which can be placed in and secured before the main conversion stop and only one which cannot be positioned until the stop. In this way foundation work is being kept down to a minimum.

DESIGN LIMITATIONS

In proceeding further with the design of the main mill, consideration was given to the latest universal mill installations, particularly those in the U.S.A. There are two main designs of vertical roll drive assemblies. In one, both roll housings and bevel gears move in and out on slides with the first motion bevels sliding along a splined drive shaft. In the other, slides are incorporated for the roll housings, but the drive gears are fixed with each roll driven through vertical spindles from overhead. In this latter application considerably more headroom is required than in the first, and a cross-section of the mill building (Fig. 5) shows that there are several limitations in installing either of these two types. The maximum lifts of the main and auxiliary crane hooks affect both the installation of the mill as well as the problem of changing the vertical roll assemblies.

It had also been agreed that the vertical roll motor would be in the motor room, and the depth of the building girders meant that the centre line of the motor was to be not more than 21 ft above floor level. On considering these two physical limitations, one for the motor position and one for the overall mill height, it was obvious that neither of the designs could possibly be used. The Company was by this time in touch with a British manufacturer and designs of a new mill were in hand. This mill had to be lower than any previously built, had to be robust enough to take the 4000-h.p. drive and to incorporate as many improvements as possible, particularly in the method of roll changing. In the early part of this year a small team went over to the U.S.A. to make a concentrated study of universal mill design, both mechanical and electrical, and to investigate further the operational angle.

As a result of all these investigations, basic designs for the mill drive were produced. There were many problems, such as whether there was to be a 1 : 1 gearbox between the motor and the main drive shaft to the mill, and what the exact reduction should be between this shaft and the rolls, and many schemes were discarded. As far as possible, the final design incorporates the better features of all known universal mills and as many improvements on these as could be made within the physical limitations imposed.

The drive from the motor to the vertical mill is through a 32-ft long supported jack-shaft to a drive shaft mounted in the drive gearbox at the top of the mill. Mounted on this shaft are two spiral bevel gears, each of 65 in. and 15 in. face. It is unfortunate that spiral gears of this face width cannot be manufactured in Britain and these represent the only items which will have to be bought from overseas. The mating bevels are mounted on a vertical shaft

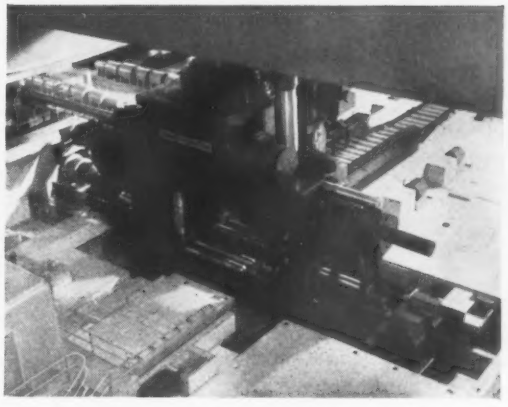


Fig. 6—Removing vertical roll assembly

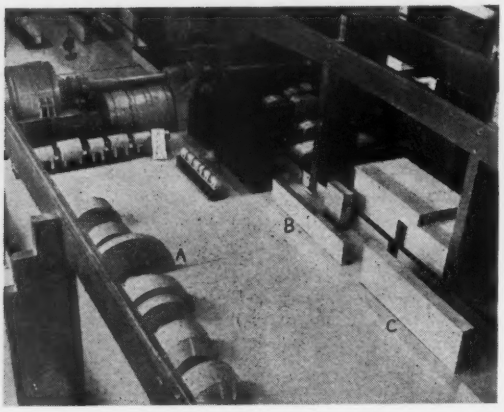
common with diagonally-pitched helical spur gears of 4 ft 6 in. pitch circle diameter and 24 in. face. The mating spur gears are 6 ft 6 in. p.c.d. giving a reduction of 1·45 to 1. The vertical roll diameters are 37 in. max. to 35 in. min., giving the correct speed matching with the horizontal roll diameters. The final drive spurs have hollow and splined centres through which the vertical spindles are driven. These spindles have an overall length of about 12 ft with a shank diameter of 14 in. They engage with the ends of the rolls in ordinary palm and slipper couplings. The bottom ends of the spindles rest in pressure pads to support their weight. The gear centres are so arranged that the spindles are vertical when the rolls are set for 47-in. opening with new rolls. For 24-in. opening the spindles are inclined at 5° and for 74-in. opening at 7° to the vertical.

This arrangement of drive does include the better features of the U.S. mills in which the bevel gears and drive are fixed and the rolls driven through vertical spindles. The angularity of the spindles is kept low and the drive incorporated in a comparatively low headroom. The bevel gears are also on the higher-speed side but this arrangement requires this very large gearbox mounted above the mill and it causes a considerable erection problem.

The roll adjustment screw speed has been determined at 207 in./min. This corresponds with the latest U.S. mills. There are two 14-in. dia. 2-in. pitch screws on each side, one on the top and one on the bottom. The drive is by two 200-h.p. motors coupled by a connecting shaft across the mill.

The roll-balancing of the vertical mill caused some concern since it is understood that insufficient balancing on some mills has caused frequent breakdowns. It has therefore been decided to instal three balancing cylinders, two fairly near the top and one at the bottom of the assembly. It is estimated that the total friction of force to be overcome will be 20 tons and the operation will be hydraulic at a pressure of about 1 ton/in^2.

The vertical rolls are mounted in chocks which rest on horizontal slides. The rolls themselves are completely reversible so that their lives can be increased considerably. The arrangement of the chocks



A horizontal rolls ligner set
B control desk and alarm panel
C open-type mill auxiliary control panel
D d.c. and a.c. main supply panels

Fig. 7—North side of motor room

and slides is such that the roll assemblies can be removed complete by the overhead crane. For roll changing the rolls are brought to their neutral position at 47 in. and the spindles disengaged vertically by built-in jacks. They can also be lifted clear by the overhead crane if necessary. The mill is then opened out until clear of the gearbox structure, and the roll assemblies removed vertically (Fig. 6).

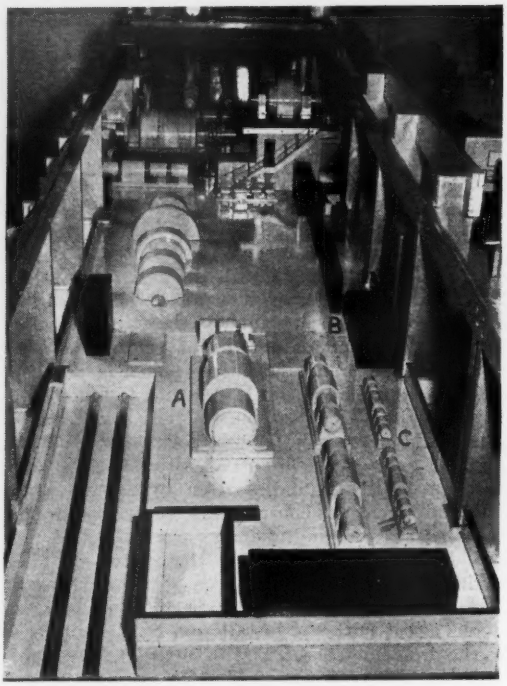
Reviewed above are some of the main items of design which have been determined: mill speed and horsepower, drive transmission, method of roll changing, screw adjustment, manipulators and roller gear. There are also the problems of lubrication, particularly in the main drive gearbox. It will be appreciated that the bearings in this box are large; for example, the final spur shaft top bearings are 55 in. i.d. and 65 in. o.d. The gears must be lubricated by sprays on both sides since the mill is reversing, and a total supply of 85 gal/min of oil will be required. This will require an increase in the oil storage tank capacity of about 3000 gal and it is intended to extend the existing system.

The edger motors and synchronous M.G. sets will also be equipped with twin-pump lubrication units with standby capacity. The requirements are 6 gal/min and 8 gal/min respectively for the journal bearings.

On the horizontal roll stand there will be very few changes. The lift will be increased from 73 in. to 78 in., but the roll diameters and chocks will be identical. We are also retaining the roller bearings for the roll necks. Advantage is being taken of the change to improve the sensitivity of the screwdown control, but its speed and drive will be unaltered. In general, if there were to be any prolonged breakdown on the vertical mill, the horizontal mill could be quickly adapted to a high-lift mill again merely by changing rolls.

UNIVERSAL MILL INSTALLATION

At an early stage in the development it was necessary to prepare a preliminary programme for the conversion of the mill. It is known that in the U.S.A. blooming mills have been dismantled and new mills installed in seven or eight days. The conversion to a universal mill is a more involved project, but from the first design stages, attention has been focused on a quick conversion time. The preparatory work can be separated into five main sections and are outlined as follows.



A synchronous M.G. set
B edger mill and M.G. set control panel
C auxiliaries exciter sets

Fig. 8—North side of motor room after conversion

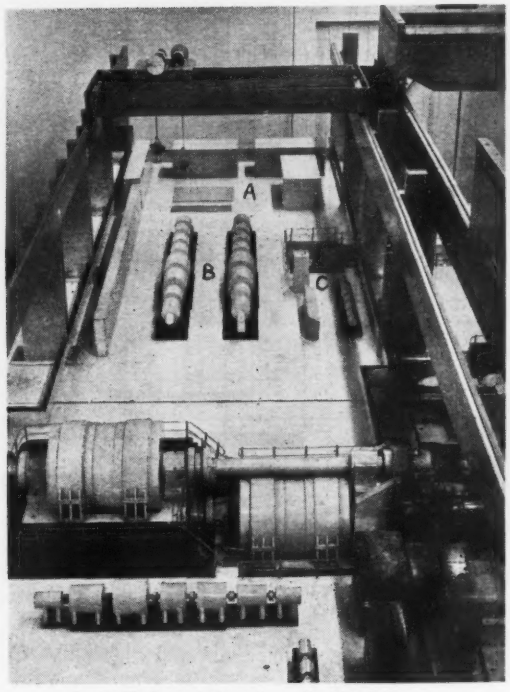
Models

Soon after the decision to purchase a universal mill, it was decided that models should be made to include not only the mill stands and tables, but also the motor room and operating floor area.

One model was then made of the area extending from the ingot-receiving table to the small vertical edger in the mill bay, and of the complete motor room, to a scale of $\frac{1}{2}$ in. = 1 ft. With this scale the area can be included on a table 12 ft × 8 ft but is sufficiently large to make it possible to dismantle the model in assemblies to illustrate the changeover programme.

A second model was also made of the new mill, manipulator and table equipment to the same scale, so that it could be erected on the same model table in place of the existing mill to illustrate the completion of the changeover. Because of the difficulties of construction, it was decided to make a third model to show in detail the alterations necessary to the foundations beneath the ingoing sole plate.

This model work cannot be completed until the design of the new mill is finished and the changeover worked out in detail. Meanwhile the models have



A auxiliaries control panel B M.G. sets
C vertical edger drive and panel

Fig. 9—South side of motor room

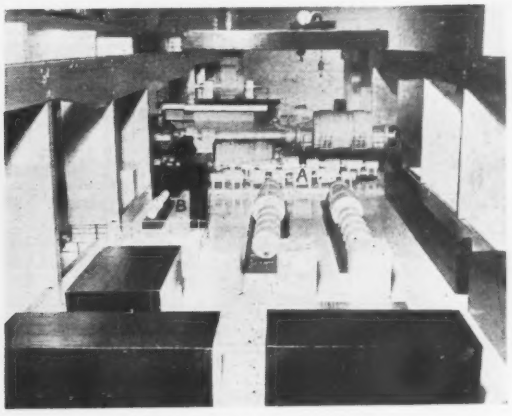
been completed as accurately as possible at this stage, and are showing up problems more clearly. As these are solved the models will be amended and finally be used to brief all personnel. The models in their present form are being used to illustrate the change-over programme and they have been photographed at the various stages of dismantling and erection. They also illustrate the changes in the motor room.

No matter how well models are made, dismantling and re-erecting them is a lengthy business and really requires a power-operated carriage in which a man may be suspended over the model. Therefore for most of the briefing it is very probable that the use of photographs of the model is better than using the model itself. Having once photographed the best way of doing the job, it is easier and quicker to use lantern slides than to dismantle and erect the models. They will, however, still be required for briefing on slinging and handling and also for illustrating movements of assemblies as they are hoisted and travelled in difficult locations.

The cost of the models, the photographs and the model room will not amount to more than a small fraction of the total job, and is already proving itself a well-worthwhile expenditure.

Motor Room Changes, Foundation, and other Preliminary Work

There are many complicated changes and additions in the motor room (Figs. 7–10). Much of the equipment adjacent to the horizontal roll motors has to be moved to make way for the new mill's edger roll motor. In other areas other equipment must be



A repositioned and standby exciter sets
B repositioned d.c. supply panel

Fig. 10—South side of motor room after conversion

moved to make room for M.G. sets for the edger motor and edger roll adjustment. Extra space is also required for additional electrical equipment to improve performance of the screwdown and manipulator gear.

This preliminary work has already started with the clearing of a site for a new substation connected to the slabbing mill motor room by a twin tunnel 100 ft long. When this substation is completed, some of the equipment in the motor room will be re-erected in it, so releasing the extra space required.

Early in the preliminary work programme, the area next to the horizontal roll motors must be cleared. The new edger motor base will occupy this space, which is now filled by the main d.c. panel and exciter sets on the floor level, and by motor cables and lubrication pipes in the basement.

The edger motor base will require 4 months for construction and the erection of the motor a further 4 months. Clearing the area and final erection will therefore extend from now right up to a month before the time of the final changeover.

As soon as the new d.c. panel and exciter sets are delivered they will be erected on the south side of the main motors, and will be brought into service gradually so that the existing equipment can be moved without loss of production. Resiting the equipment will permit the main motor cables to be run along different routes, thus clearing the area in the basement required for the edger motor base. The 3·3-kV switches and the d.c. and a.c. boards will have been removed to the substation.

Another big addition to motor room equipment is the synchronous motor-generator set for the vertical roll motor. This can only be positioned in the north side of the room and will actually occupy an area now used for the storage of spare armatures and other equipment. These must now be stored elsewhere.

The programme for the new electrical installations is shown in Fig. 11 and indicates what has to be done between now and the mill conversion.

Many of the alterations to the slabbing mill foundations will also be completed well before this time. For example, the pass line of the universal mill will be 2½ in. lower than that of the existing mill,

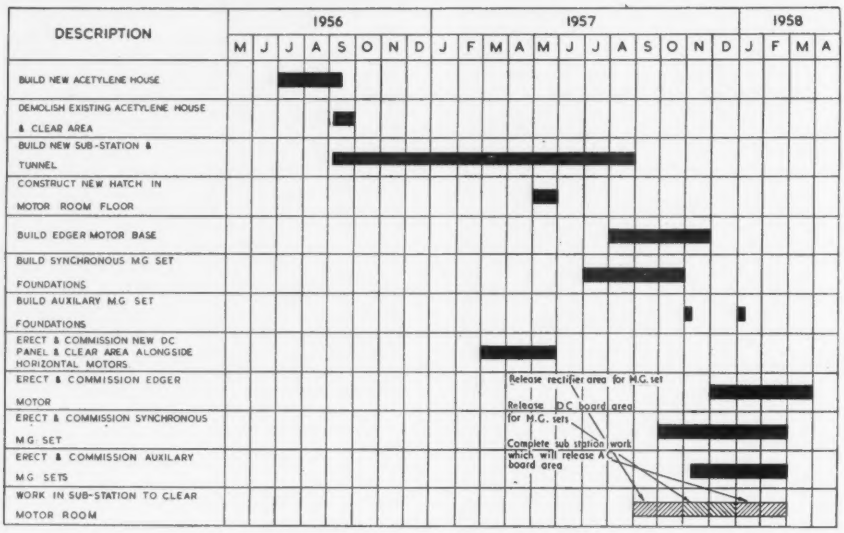

DESCRIPTION
1956
1957
1958
M J J A S O N D J F M A M J J A S O N D J F M A
BUILD NEW ACETYLENE HOUSE
DEMOLISH EXISTING ACETYLENE HOUSE & CLEAR AREA
BUILD NEW SUB-STATION & TUNNEL
CONSTRUCT NEW HATCH IN MOTOR ROOM FLOOR
BUILD EDGER MOTOR BASE
BUILD SYNCHRONOUS M.G SET FOUNDATIONS
BUILD AUXILARY M.G SET FOUNDATIONS
ERECT & COMMISSION NEW DC PANEL & CLEAR AREA ALONGSIDE HORIZONTAL MOTORS
ERECT & COMMISSION EDGER MOTOR
ERECT & COMMISSION SYNCHRONOUS M.G SET
ERECT & COMMISSION AUXILARY M.G SETS
WORK IN SUB-STATION TO CLEAR MOTOR ROOM
Release rectifier area for M.G. set
Release D.C board area for M.G. sets
Complete sub station work which will release A.C board area

Fig. 11—Programme for electrical plant

and to cater for this it is necessary to lower the roll-change rig $2\frac{1}{2}$ in., and this will be done during the preliminary work. The rig supports will be lowered by cutting away concrete from beneath them, but will remain packed up on steel stools until the changeover has taken place.

The new sole plate for the edger mill will extend on the entry side of the mill and will require additional holding-down bolts. These have to be 6 in. dia. with at least a 6-ft grip. To cut holes for them during the changeover would take a very long time. It has therefore been decided to make use of some of the access and air tunnels beneath the mill foundations and to cut holes and chases from underneath and so prepare the bolt holes in advance. To make room for the sole plate itself it will be necessary to cut out concrete, but this will not be possible until the existing mill is dismantled.

On the operating side of the mill, and in line with the edger rolls, will be the base and supports for the vertical roll adjusting screw drive and for the feed rolls. These are at a level lower than the existing mill floor and it will be necessary to cut out an area of floor and extend the roll-change pit. The new floor will be supported by a base built from the basement floor 12 ft below. This work will also be done before the changeover and will be arranged so that there is the minimum interference to the use of the mill floor area.

The new manipulators will require seven extra holding-down bolts in the area alongside the drive side of the ingoing table. These are $2\frac{1}{2}$ in. dia. with a grip of $2\frac{1}{2}$ ft, and, since it is not possible to bore holes for these whilst the mill is working, it will be done a little at a time during the maintenance stop shifts. Unfortunately, there are no tunnels beneath the foundations where these bolts are to go and it will be necessary to taper out the holes at the bottom to provide a key on to existing concrete.

The new manipulator rack-pinion drive bases will be held down by existing bolts and one additional $2\frac{1}{2}$-in. bolt which will be located in a position which cannot be uncovered until the existing bases are removed.

On the mechanical side, preliminary work will include alterations to the rack drives so that they are ready to receive the new high-speed synchronizing shafts which will be adopted with the new mill. The motor pinion shafts will be removed and new ones put in with extensions protruding out the other side of the gear box, with couplings for connecting to the high-speed synchronizing shafts during the changeover.

The grade of oil used in the vertical mill gear box and other auxiliary boxes will be the same as that used on the existing manipulator drives and will be taken from the present system. However, it will be necessary to enlarge it from 175 gal/min with 5000 gal storage, to 260 gal/min with 8000 gal storage. The extra 85 gal/min pumping capacity is easily provided but there are some difficulties with the provision of extra storage capacity. In view of space limitations, it will be necessary to add a 3000-gal section, of perhaps a rather queer shape, to the existing storage tank. It will also be necessary to increase or duplicate some pipe runs, but this work will be completed before the final changeover. In addition, extra automatic grease-lubrication equipment will be required to work in conjunction with existing equipment, to supply the new mill.

Special Lifting Beams, etc.

To dismantle the mill in large assemblies, in very quick time, it will be necessary to provide many special tools and tackle. Some of the tools, lifting beams, and lifting tackle which will be required will take a long time to make and designs therefore have been started already.

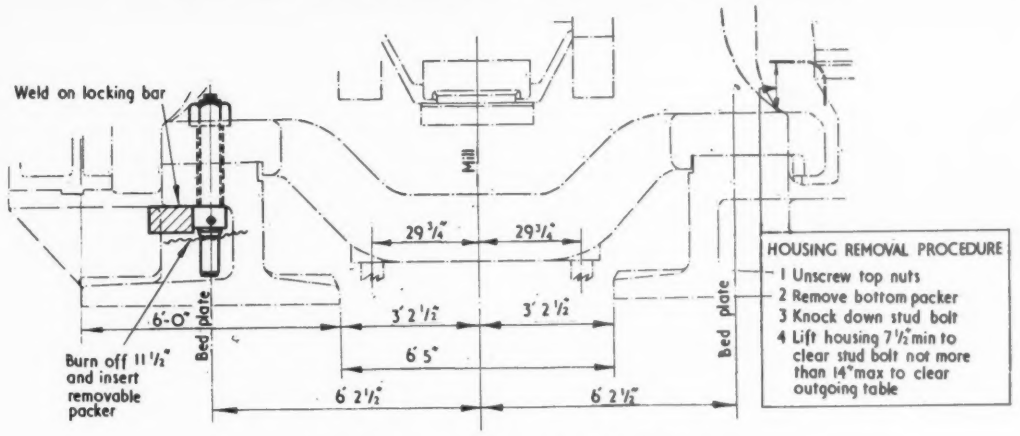


Fig. 12—Housing feet and stud bolt detail

The arrangement of some of the securing bolts and nuts precludes the use of air wrenches, and for others it will be necessary to move auxiliary equipment to get at bolt heads. Most of the bolts concerned have already been examined and special spanners will be made and welded into place to be left until the conversion. This will locate one end of the bolts. For further work on the other end, it is intended to use air wrenches wherever possible, even up to nuts for 6-in. bolts, and these large wrenches will probably be imported from the U.S.A. Since most of the bolts which have to be handled are 2½ in. and over, it will not be possible to obtain a wrench to deal with all locations, but special attachments can probably be obtained for most of the applications.

In the case of the mill housing holding-down bolts, it will be necessary to burn off a portion from the bottom of each 6-in. stud bolt some time before the changeover so that when the nut is slackened off the stud can be knocked down. This is an example where it will be necessary to weld on locking bars to prevent the stud bolts turning, as is shown in Fig. 12.

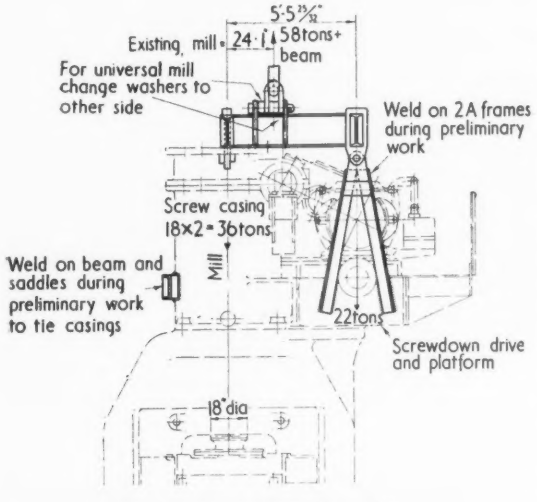


Fig. 13—Screwdown lifting beam

Special lifting beams will be required for dismantling and erecting many of the assemblies. Early during the dismantling the whole screwdown structure must be removed, complete with drive and motors, weighing 58 tons, and to do this it is necessary to have a special lifting beam. The screwdown structure consists of two screw casings and a drive platform which sit separately on top of the housings posts, but are connected by flanged facings. To lift this assembly without a beam would introduce bending around the flange facings between the casings and the platform. Figure 13 illustrates how it is proposed to lift the assembly, with an indication of the weights.

When the existing mill was erected, the mill housings, which weigh 108 tons each, were put in with two 85-ton cranes and special lifting beam. With the new 130-ton crane it will be possible to make a much simpler lifting appliance, which will fit into the space normally occupied by the screw box. It will also be possible to arrange a shackle fitting in the appliance so that the housing can be lowered flat on a railway wagon to clear the load quickly from the mill. The housings have a flat base 4 ft wide, which means that a force of approximately 8½ tons will have to be applied to the top of the housing to tip it. This will be provided by an auxiliary winch.

Later in the dismantling programme, 14 ingoing table rollers are to be removed. These assemblies weigh only 7½ tons each but if they are lifted out one at a time and taken clear of the mill with the crane, a great deal of time would be wasted. To overcome this, special lifting beams approximately 15 ft long (Fig. 36) will lift 5 rollers at a time, so reducing the number of lifts from 14 to 3. Two cranes and two beams will be used so that time is not lost when the rollers are being unhooked.

The three different types of lifting beams mentioned will be as useful for erection as they will be for dismantling. The weights of the screwdown structures for the new mill will not be exactly the same as for

the existing one, but this can be overcome by provision of a second lifting point on the beam.

During erection the weights of assemblies will be heavier than during dismantling, but with one exception they can be made with the 130-ton crane. The exception is the new vertical roll drive gear box, which complete with gears and supporting beams may weigh up to 200 tons. This design is being investigated closely to ensure that erection can be made as simple as possible. The maximum lift which can be made by two 85-ton cranes is 170 tons, which, by the use of a lifting beam approximately 45 ft long and 15 tons in weight, is reduced to 155 tons. The gear box, therefore, may have to be divorced from its supports, or some of the gears left out during the lift. This is complicated by trying to make the box of good design yet easy to maintain and also easy to erect. The maximum lift of the crane hooks is only 7 ft above the top of the gear box when erected, which is a further difficulty.

As well as lifting beams, many other clamps and tools will be needed. The screws for the horizontal rolls will be removed with the housings, and for a long period will have to remain in the housings with special clamps which can be put on and removed quickly and easily.

The vertical edger sections of the new mill are held together by bolts 14 in. dia. × 36 ft long, some of which have to be threaded through the entablatures, beams, and housings after they have been erected. To make this as easy as possible, tubes will be welded inside the cored-out entablatures and beams, which will be greased internally to make it easy to draw the long bolts through. Special attention will also be paid to the design of the bolt ends so that the nuts can be threaded on easily.

Moving the large masses mentioned will require auxiliary winches for positioning and control. Anchor blocks for these will be put in when the motor base and mill floor alterations are made.

Design Discussions with Manufacturers

It is normal practice during the design of new equipment as large as a universal mill, for the customer and mill manufacturer to discuss the design at every stage. It is always important, not only for the customer to give his requirements for the design for improvements and easier maintenance, but also to give the manufacturer the benefit of his experience and knowledge of site conditions. When the new equipment has to be installed into an existing production line this practice is absolutely essential.

Previous experience has shown that much time has been lost during erection because pipework, ducting and electrical equipment was not pre-erected with the main plant at the manufacturer's works. In this case it is intended that everything will be pre-erected and match marked for reassembly and will be labelled in colour for easy identification. It has also been found that over-zealousness in re-using old parts for economy has often resulted in longer erection times because these parts are invariably not only worn, but are also not quite right for matching to the new equipment.

The pre-erection of the equipment at the manufacturer's works will also be a useful erection rehearsal. Photographs of the pre-erection will be used later for briefing to illustrate slinging and handling, and the timing of the pre-erection will enable the final programme to be confirmed. During the pre-erection, special tools, slings, etc. will be used and then labelled for use again on exact lifts during the final assembly.

Key personnel will be sent to see the mill erected and dismantled in the maker's works and to discuss the erection.

Detailed Planning

During the next eighteen months, the main programmes for effecting the mill conversion will be worked out in great detail. This will involve not only the engineering department but also the personnel and transport departments, who will play a very important role in the work. The control organization in charge of the job will include senior members of these and of the rolling mill management, so that decisions can be made immediately if something unforeseen necessitates a change of the programme.

There will be one engineer in charge of the whole operation with a chief planning assistant responsible for keeping everyone up-to-date with the programme and making any necessary amendments. In addition, a design engineer who has been involved with the mill design since its inception will be able to solve any design question as it arises and authorize any modifications immediately.

One engineer will be in charge of the dismantling and erection work on each shift, assisted by civil and electrical engineers. Other assistants will be responsible for supervision of individual assembly work and for the flow of lifting appliances, tools, and rigs to and from the mill in the correct sequence.

Senior members of the transport staff will, in addition to supervising the flow of vehicles and rail wagons, be responsible for transport of the shift men to and from the plant at the right times. Attention will also be given to the provision of meals.

To ensure that the final programme is realistic, many planning exercises will be carried out between now and the conversion stop, which will enable individual job times to be established. As many as possible of the securing nuts and bolts on the existing mill will be slackened off and replaced. Those which cannot will either be burnt out and renewed or marked for burning out during dismantling. In the same way, lifting times can be checked for dismantling and the manufacturers will follow the same procedure during the first erection of the mill.

All new equipment will be laid correctly on the mill floor as near as possible to the mill. As the existing mill is being dismantled the assemblies will be carried beyond this and transferred out of the building as soon as possible. Many details of the handling have yet to be worked out and, owing to the large weights of some of the equipment, floor loadings must be carefully checked before the storage and disposal area plans are finalized.

One problem is the handling of the large nuts and bolts. A possible suggestion is that rather than keep large bolts and nuts made up in pairs in boxes, the nuts may be tack welded in place during pre-erection.

The bolt can be similarly attached in the correct position on the casting or piece and the weld easily broken off for the bolt to be entered into the nut during erection. This would save double or treble handling and ensure that pairs of bolts and nuts are kept together. Almost all the nuts and bolts used are over 2 in. dia. and many are 4 and 6 in., so that reducing handling to a minimum will save much time and energy.

When design details are finalized and these experiments have been carried out, it will be possible to produce a programme where the number of men necessary can be matched against the best sequence of operations. Meanwhile the programme sequences are being arranged to absorb the majority of the available men continuously. This comprises two main groups of men. One group would prepare an assembly for dismantling while the other is removing bolts and nuts on another job prior to dismantling. Since many of the lifts require 85-ton cranes, and two such cranes cannot stand over the mill and the tables at the same time, slinging and picking-up times must be kept to a minimum. Mobile swinging-jib cranes and hoist blocks will be employed, but for the main part the programme must follow the two main lines of unbolting followed by dismantling during the dismantling period and of placing and levelling followed by final securing in the erection period.

At present it is estimated that there will be about 115 men per shift made up as follows:

2 Central Mill Gangs of 20 each (One on erection or dismantling, one on bolts)	40
North Area Assembly Gang	10
South Area ,, ,,	10
North Area Riggers	5
South ,, ,,	5
Welders and Burners	20
Pipefitting Gang	10
Civil Engineering Gang	5
Electrical Gang	10
	115

The number of civil and electrical workers will have to be greatly increased at some points of the programme.

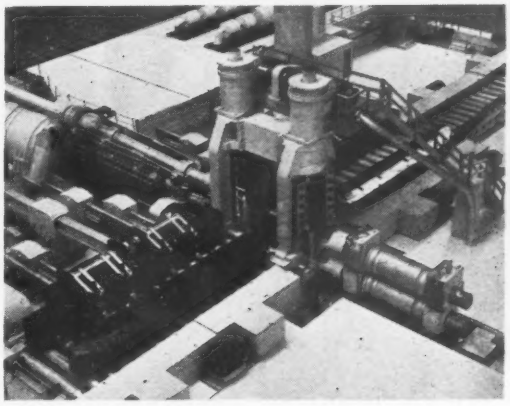


Fig. 15—Rolls removed from mill

Preliminary Programme

Based on present knowledge and the experience of others, it is estimated that this work can be carried out in a period of 15 days from the shutdown to start-up. Of this, 56 h are required for dismantling the existing mill and the remainder for erecting the universal mill and auxiliaries. This is based on working a three-shift rota throughout each day.

To illustrate the stages of the work, photographs have been taken of the models. Figure 14 shows the existing mill with roll-change pit covers removed. It will be noted that scaffolding has been omitted, so that the mill can be seen clearly, but in practice it would have been erected prior to commencing the job. In addition the floor area would be covered with equipment, tools, and stores laid out in advance. The model does not show the preliminary foundation work which will have been completed near the roll-change pit.

Figure 15 shows the rolls out and the top screw domes removed. Whilst the roll assemblies are being lifted away, the screw hoist will lower the screws and boxes on to the bottom of the housing windows where they will be secured and will remain until they are lifted out with the housing later. The roll

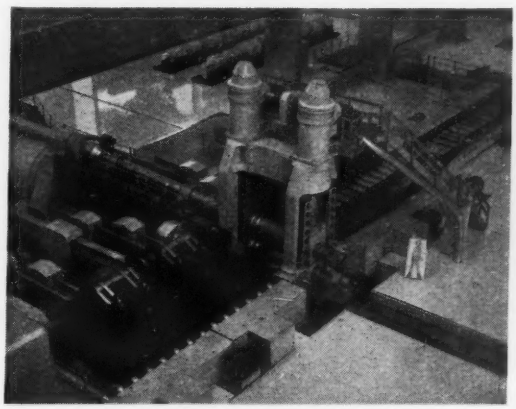


Fig. 14—Existing slabbing mill model

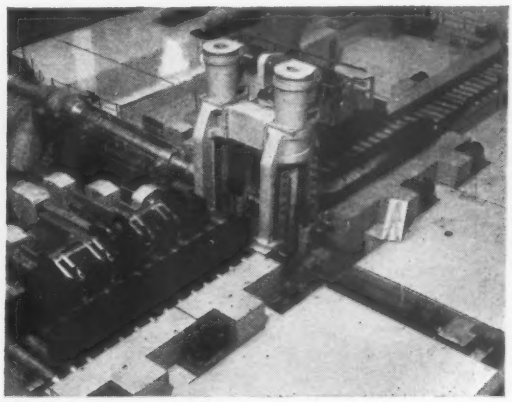


Fig. 16—Screwdowns disengaged

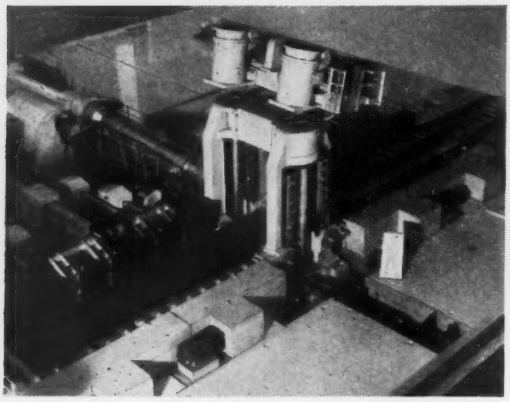


Fig. 17—Screwdown gear removed

balance rods will also be lifted out of engagement and secured to the housings. Figure 16 shows this and that the air ducts, access stairs and pipes have been removed. Figure 17 shows the removal of the screwdown casings and platform which will be done with the special lifting beam. This operation is expected to take 3½ h.

At this stage the two entry and delivery breast rolls must be removed. Those farthest from the work rolls are accessible by taking off the bearing caps, but the other two have to be drawn through the housings. They weigh approximately 7 tons each, and in Fig. 18 three of the rolls are out and the last one is being removed with a porter bar. For this a hot-strip mill work-roll porter bar is used with a special adaptor. This will take about 8 h, and during this time the bottom mill separators and the outgoing table stool will be burnt out. To remove the top separator by unbolting will take a long time but it can probably be burnt with a special torch in 30 or 40 min. It is of box section, approximately 16 ft around and 2½ in. thick.

Figure 19 shows the roll-change rig and rails taken out and the housings free and ready for lifting as soon as the last holding-down bolts are removed. The nuts have to be taken off the 6-in. jack bolts, the bolts knocked down and the housings lifted approximately 10 in. to be clear.

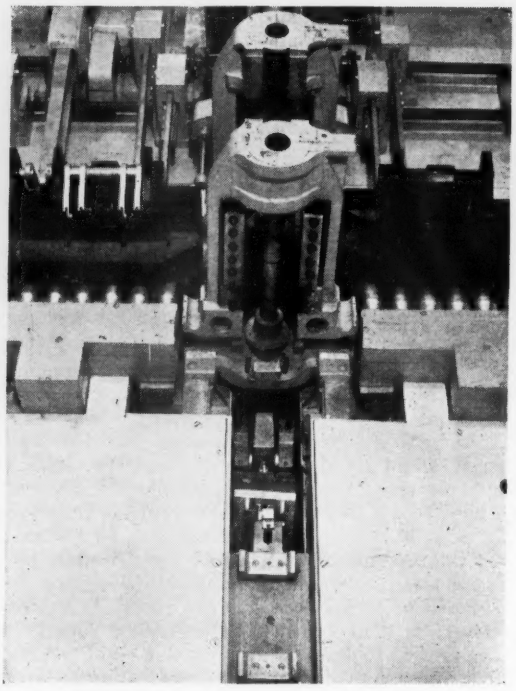


Fig. 19—Housing ready for removal

If the separator has been cut in the middle, the drive-side housing will be removed first by taking it towards the motor room after lifting to clear the tables. The operating-side housing can then be lifted clear of the bolts, moved slightly towards the motor room and taken out. This lateral movement is due to the tables protruding and preventing a direct vertical lift.

Figure 20 shows the operating-side housing lifted clear and exposing the sole plates. It is now in its correct position for lowering on to a railway wagon

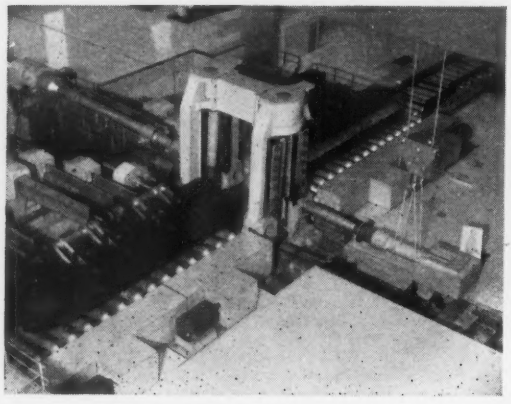


Fig. 18—Feed rollers removed

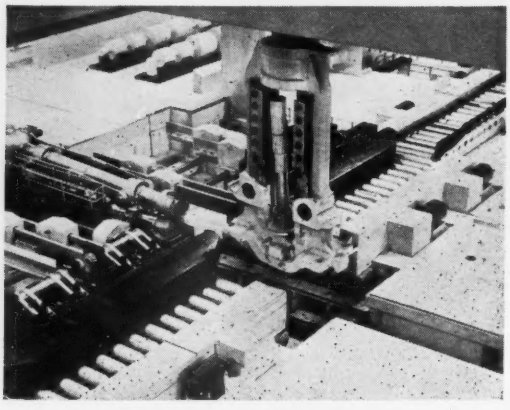


Fig. 20—Housing being removed

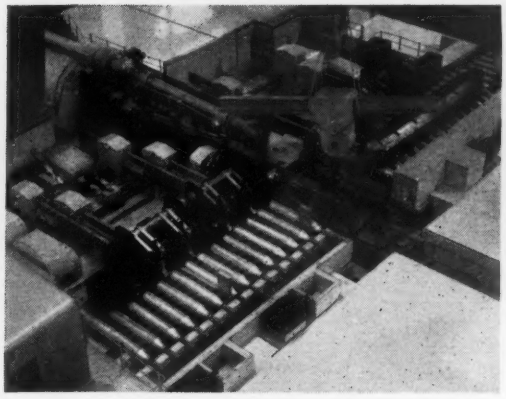


Fig. 21—Manipulator rack being removed

which will be berthed in tracks nearby. The sole plates will remain in place until the ingoing table and manipulators have been removed.

This work will have take a total of 25 h. To strip the manipulators and tables, the operating-side guard and table covers are removed first, exposing the table roller gear and bolts. Figure 21 shows this completed and the crane lifting off the finger rack beam and drive weighing 15 tons and 31 ft long. The drive-side manipulator head and fingers can then be removed (Fig. 22). The dismantling time for the remainder of this equipment will be short since most of the securing bolts will have been removed during the dismantling of the mill.

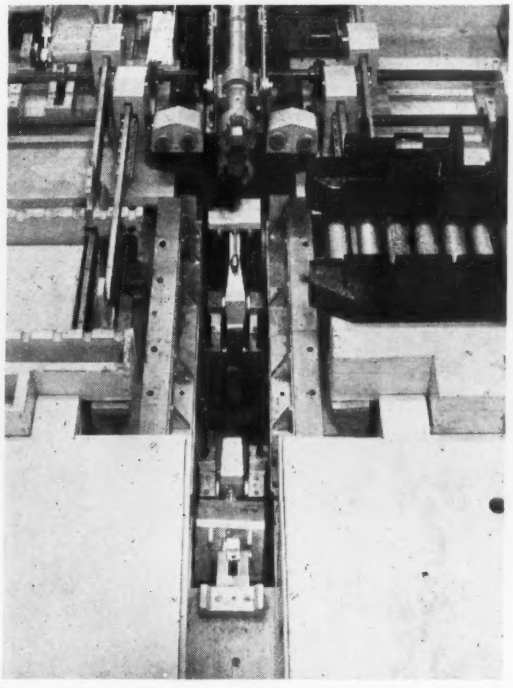


Fig. 22—Mill tables dismantled

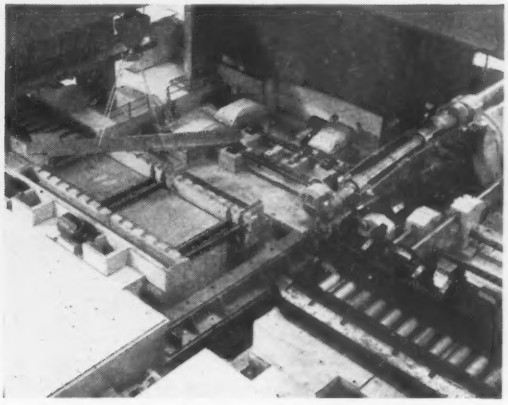


Fig. 23—Manipulator beam being removed

Figure 23 shows the last of the rams being lifted away, complete with its driving rack, and it weighs $12\frac{3}{4}$ tons and is 35 ft long. Before lifting out the manipulator drives which are now exposed, the drive side table and the ram support beams will be removed in one lift of $26\frac{1}{2}$ tons, measuring 36 ft long and 18 ft 9 in. wide. This assembly will be taken to the disposal area at the south end of the mill for further dismantling before being removed from the building.

The section of the table drive casing next to the mill can now be lifted out, finally releasing the ingoing sole plate complete with table stools (Fig. 24). This is one of the biggest dismantling lifts, being 30 ft × 8ft × 6 ft wide and weighing 60 tons. This second period will have taken a further 21 h, and the final dismantling involves the removal of the ram drive shafts and the rack pinion bases. At this stage, foundation alterations can commence.

Figure 25 shows the programme for all the foregoing work, during which period approximately 1000 tons of plant will have been removed.

A block of the foundations of the existing mill (Fig. 26) on the ingoing side has been made with two removable sections on top to illustrate what must be removed for the universal mill sole plates. The additional bolts into the access walkway and air

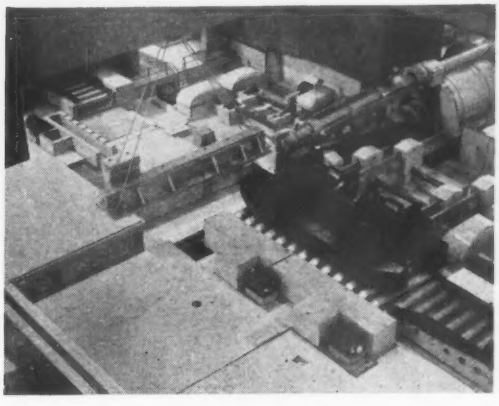


Fig. 24—Housing sole plate being removed

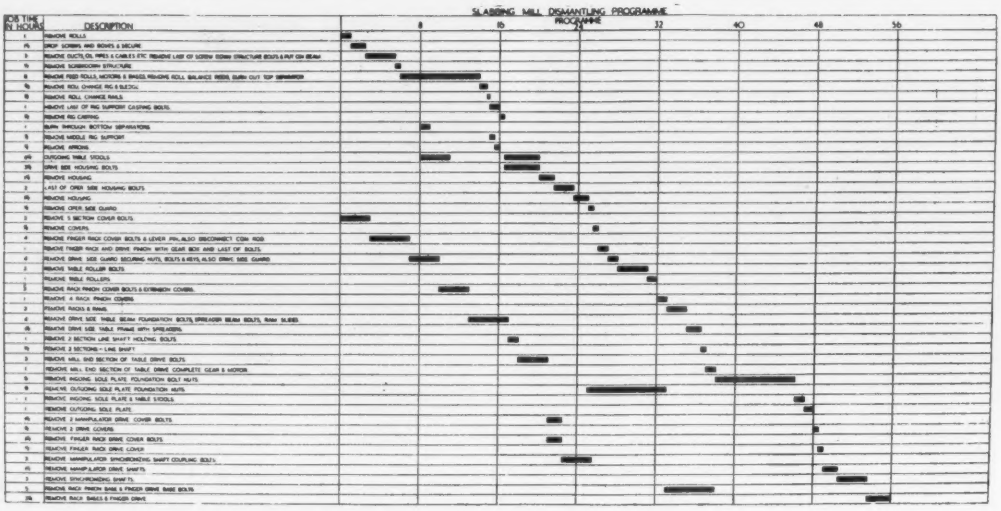


Fig. 25—Slabbing mill dismantling programme

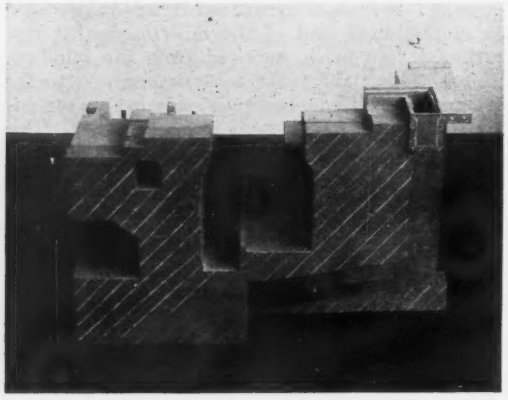


Fig. 26—Foundation block model

tunnel and most of this work will have been done beforehand. It will be necessary to break through finally when the rest of the concrete has been cut away, as shown in Fig. 27. The mill sole plates have been designed so that no fresh concrete need be poured. Existing concrete will be cut away, thus ensuring a solid foundation. Two pre-set levelling blocks will have been installed when the roll-change pit is extended, and they will indicate the top level of the new sole plates. These will enable rough levelling to be done quickly and final checking only will be made with levels and optical instruments.

Figure 28 shows the large ingoing sole plate, weighing 130 tons, being lowered into position. Figures 29 and 30 show the two horizontal mill housings in position on the sole plates with separators. The position of these two housings across the mill will finally position all other equipment, and at this

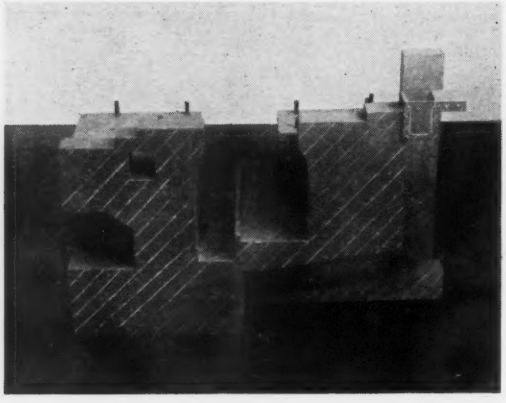


Fig. 27—Foundation block showing alterations

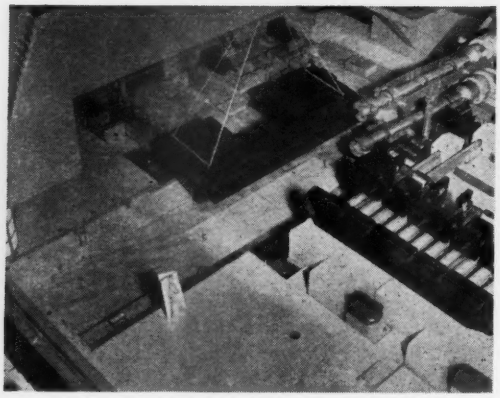


Fig. 28—New sole plate being installed

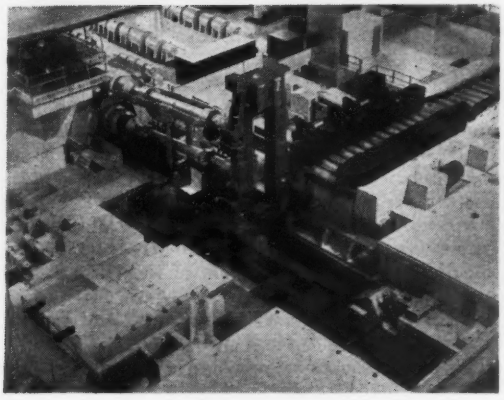


Fig. 29—New main mill housing installed

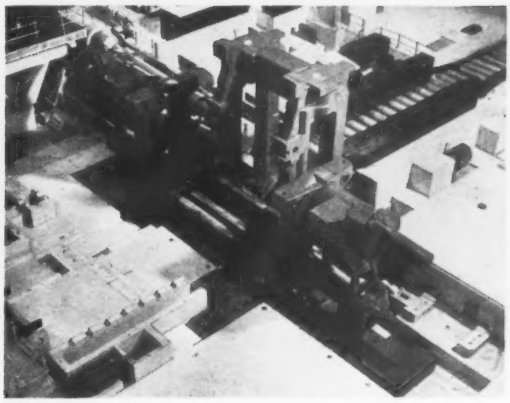


Fig. 31—Second vertical roll entablature and feed rolls in position

stage the sole plates will be checked again for level to ensure that there has been no movement after the installation of approximately 240 tons. Figure 30 also shows the drive-side vertical mill entablature complete with the screw-in gear and roll-balance gear which is installed immediately after the final level check.

The operating-side entablature with screw-in gear is shown completed in Fig. 31. These assemblies weigh approximately 100 tons each, and when they are in position it will be possible to put in the bottom spreader beams (which are also the guide beams for the vertical roll chocks) and the three feed rolls. On the programme 9 h have been allocated for installing each entablature and screw gear, and this time is considered necessary since it will be difficult to make small adjustments on such a large mass when hanging from a crane. Guide faces will be incorporated on the sole plates to make positioning automatic and for any small movements anchor blocks will be fixed on the base of the vertical drive motor and in the extension to the roll-change pit, and hand winches will be used.

In Fig. 32 the top separators and guide beams are in and the last of the tie bolts is being fed through the assembly. These tie bolts weigh 9 tons each and are 36 ft long and 14 in. dia., with a hole running right through the middle to be used for warming them. This will be done using either steam or oil, to reach a

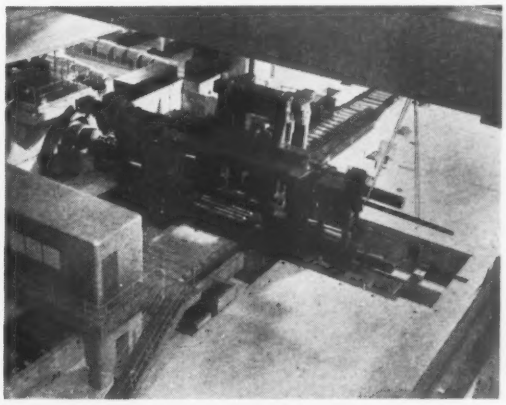


Fig. 32—Main tie rod being inserted

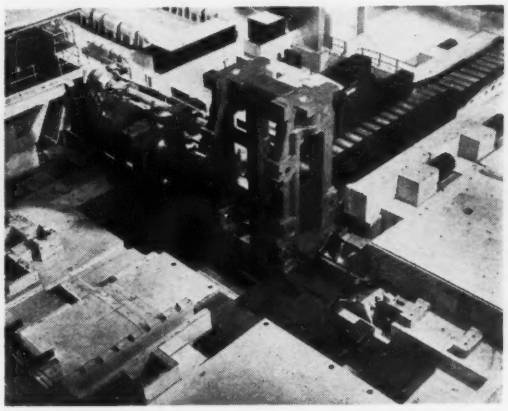


Fig. 30—First vertical roll entablature in position

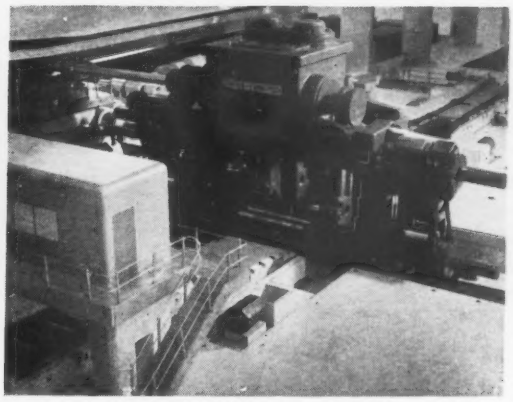


Fig. 33—Vertical roll drive box in position

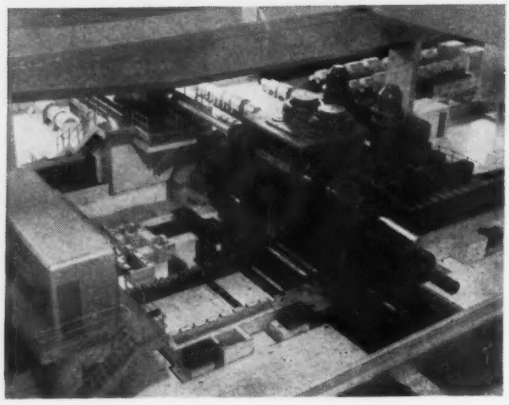


Fig. 34—Mill completed

temperature approximately 80°F above ambient. The nuts fitting on to the end of the screws are round and will have a clamping device for a wire rope to be attached to them, looped round the nut, and then pulled off with a winch. This operation finally sets the mill solidly in place, ready to receive the vertical drive, screwdown gear, and feed roll drives (Fig. 33). The erection of the gear box into position will take approximately 18 h, but most of this time will be taken in slinging the lift and moving it very slowly into position. Once it is landed on the beams the cranes will be released while bolting up is proceeding. Exact assembly procedure will depend on the final design arrangement. The installation of the main drive shaft may also take about 8 h since it must be fed carefully into position beneath the crane gantries with very limited headroom. The drive-end coupling projects well above the bottom of the crane gantry, making it necessary to take the shaft in from one side of the bearing blocks at low level and then lift it and move it into the bearings.

The complete screwdown assembly will be lifted into place in a manner similar to the dismantling procedure, using the special rig. When the screwdown is in position, the screws and nuts can be lifted into the housing and the screwdown drive gear completed. At this stage the vertical rolls can be installed and it will be possible to commission all the universal mill equipment, main drives, screw adjustment gears, feed roll drives, etc. The time taken should be approximately 10 days from the mill shutdown, when the stage shown in Fig. 34 should be reached.

During the mill commissioning, which includes final connecting up of pipework and cabling, the ingoing tables and manipulators will be assembled and erected. The manipulator drive gear box will have been installed, levelled and grouted while the vertical mill entablatures were being bolted up, since a crane will be available at that time. The light-end table frames and separators will then be installed, and accurate lining and levelling will take relatively longer than many of the main mill assemblies. At the same time, however, the manipulator rack drive shafts and covers will be put in. In Fig. 35 the main manipulator head and finger tilts are in position, and in Fig. 36 the table rollers are being lowered in. The lifting rig will enable the crane to be released quickly for other work during the time taken in bolting down the roller bearing cartridges and drive assemblies.

The completed mill is shown in Fig. 37. A plan view of universal mill and motor room is shown in

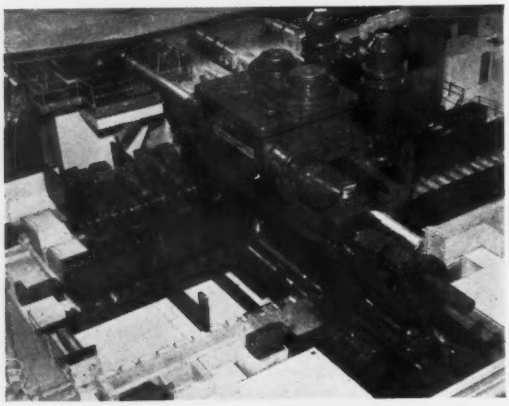


Fig. 35—New manipulator in position

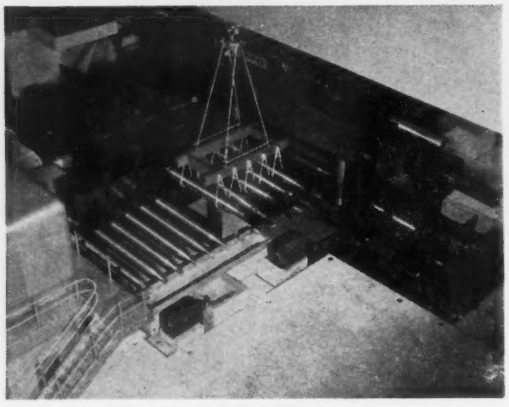


Fig. 36—Table rollers being installed

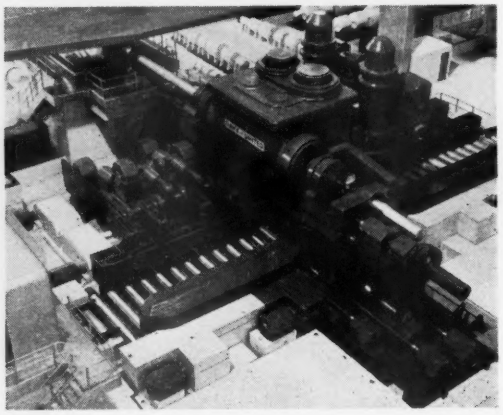


Fig. 37—Complete universal mill

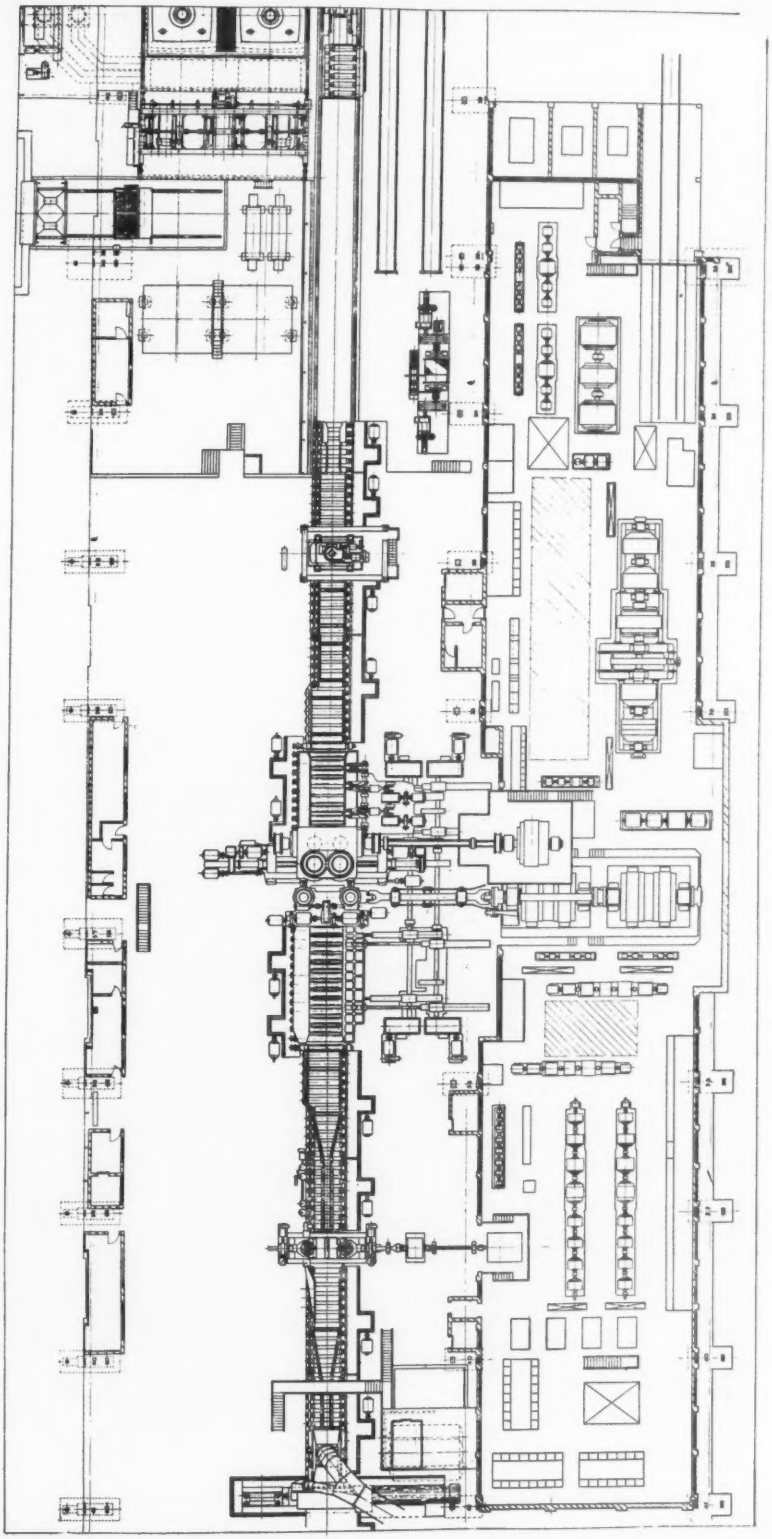


Fig. 38—Plan of new universal mill

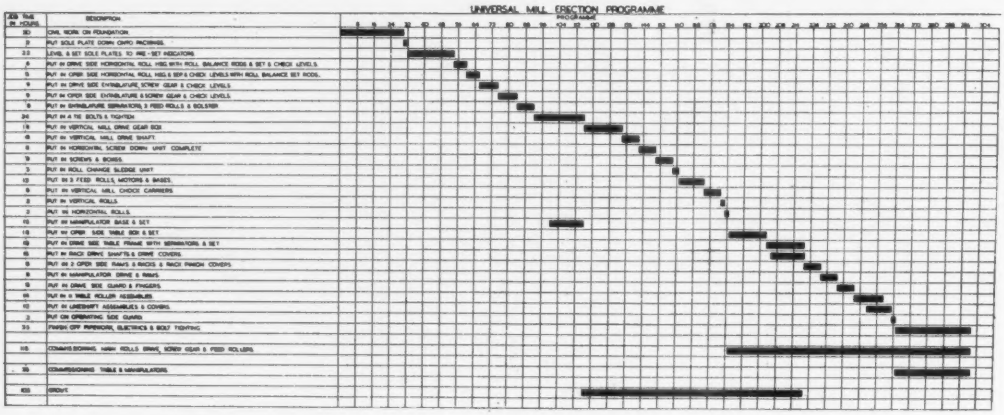


Fig. 39—Universal mill erection programme

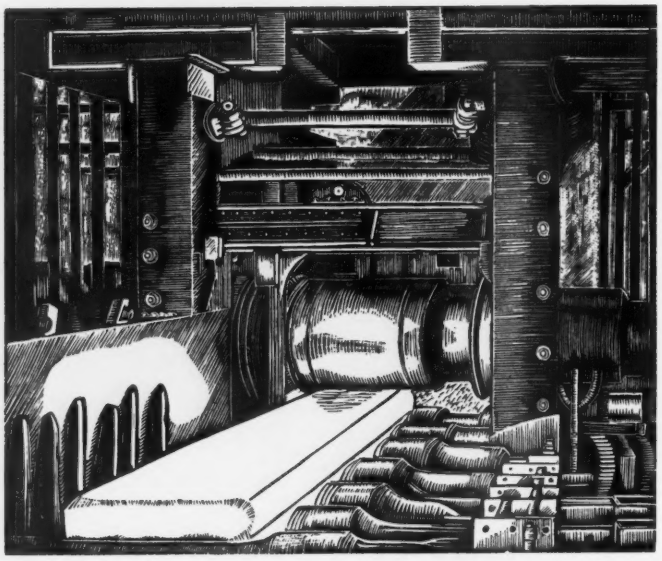
Fig. 38. A further 36 h has been allowed for final commissioning of the manipulators and tables, and the whole programme is shown in Fig. 39.

CONCLUSION

In a period of 14 days 21 h it is hoped to dismantle 1000 tons of existing plant and erect about 2000 tons of new equipment. The programme which has been outlined has already been examined in detail, and throughout the next 18 months it will be discussed and planned with all engineers, foremen and key personnel. The mill design is approaching finality, but during its manufacture and pre-erection it will be studied closely for any improvements which may assist in a fast erection. Great attention will be paid to safety by the provision of adequate scaffolding and working platforms and in the precautions taken in the preliminary work in the motor room. The accuracy of the programme will only be known after the universal mill is in operation, but it is considered that with close co-operation and efficient planning the conversion can be achieved in under 15 days.

Acknowledgments

The authors would like to express their thanks to Messrs. Davy and United Engineering Co., Ltd., and to the carpenters and photographic department of the Steel Company of Wales, Ltd., who have been of great assistance in the preparation of this paper.



N E W S

Announcements and News of Science and Industry

IRON AND STEEL INSTITUTE

Changes on Council

The following elections have been made by the Council:

Vice-President: Mr. E. Julian Pode

Member of Council: Mr. E. W. Colbeck, M.A.

Awards and Prizes

The following awards and prizes have been made by the Council. The presentations will be made at the Annual General Meeting on 22nd May.

Bessemer Gold Medal for 1957: Professor Dr. R. Durrer (Louis de Roll Ironworks Ltd., Gerlafingen)

Sir Robert Hadfield Medal for 1957: Mr. J. Glen (Colvilles Ltd.)

Andrew Carnegie Silver Medal for 1956: Dr. J. Wilcock (Liverpool University), for his paper on "Reactions Involved in the First-Stage Graphitization of Iron–Carbon–Silicon Alloys" (*Journal*, January, 1956), written in collaboration with Dr. W. S. Owen, who was not eligible for an award.

Williams Prizes for 1956: A prize of £100 to Mr. H. H. Ascough (Steel Company of Wales Ltd.), for his paper on "Maximum Utilization and Problems of Wide-strip Rolling and Sheet Finishing Equipment" (*Journal*, September, 1956).

A Prize of £50 to Mr. R. H. Slade (Steel Company of Wales Ltd.) for his paper on "Soaking Pit Practice at the Abbey Works of the Steel Company of Wales Ltd." (*Journal*, January, 1956).

Ablett Prize for 1956: A prize of £100 to Mr. R. M. L. Elkan (Loewy Engineering Co., Ltd.) for his paper on "Modern Forging Presses and Their Control" (*Journal*, February, 1956), written in collaboration with Mr. J. T. Lewis, who was not eligible.

Annual General Meeting, 1957

The programme of the Eighty-eighth Annual General Meeting of the Institute, which is to be held at 4 Grosvenor Gardens, London, S.W.1, is as follows:

Wednesday, 22nd May

9.45 A.M. to 10.45 A.M.	Formal Business Report of Council and Accounts for 1956 Presentation of Medals and Prizes
10.45 A.M. to 11.45 A.M.	Induction of new President, Mr. A. H. Ingen-Housz Presidential Address
11.45 A.M. to 12 NOON	Interval
12 NOON to 1.15 P.M.	Discussion on: "*A Century of Cowper Stoves*," by D. Petit (April, 1957)
1.15 P.M. to 2.15 P.M.	Buffet Luncheon
2.15 P.M. to 3.30 P.M.	Discussion on: "*Effect of Alloying Elements on High-temperature Tensile Strength of Normalized Low-carbon Steel*," by J. Glen (May, 1957)
3.30 P.M. to 4.45 P.M.	Joint discussion on: "*The Strain Ageing of Boron-treated Low-carbon Steels*," by E. R. Morgan and J. C. Shyne (February, 1957) "*The Physical Metallurgy of Low-carbon Low-alloy Steels containing Boron*," by K. J. Irvine, F. B. Pickering, W. C. Heselwood, and M. Atkins (May, 1957)
7.0 for 7.30 P.M.	Members' Dinner at Grosvenor House, Park Lane, W.1 (*Dress:* Evening dress; decorations will be worn)

Thursday, 23rd May

10.0 A.M. to 11.30 A.M.	Discussion on: "*Combustion and Heat Transfer in an Open-hearth Furnace*," by (the late) S. W. Pearson, M. W. Thring, and J. H. Chesters (Special Report No. 59)
11.30 A.M. to 11.45 A.M.	Interval
11.45 A.M. to 1.15 P.M.	Discussion on: "*Co-operative Trials on All-Basic Furnace Roofs*," by the All-Basic Furnace Sub-Committee of B.I.S.R.A. and B.C.R.A. (March, 1957)
1.15 P.M. to 2.30 P.M.	Buffet Luncheon
2.30 P.M. to 4.30 P.M.	Joint discussion on: "*Thermal Changes in Steels as shown by Resistivity*," by G. Bullock (Aug., 1956) "*The Effect of Quenching on the Thermal Conductivities and Electrical Resistivities of Steel*," by R. W. Powell (September, 1956) "*The Effect of Oil Quenching and Tempering on the Thermal Conductivities and Electrical Resistivities of Three Steels*," by R. W. Powell and R. P. Tye (September, 1956) "*Thermal Conductivity and Electrical Resistivity of a 0·4–0·5% Manganese Steel*," by R. W. Powell and R. P. Tye (November, 1956) "*Specific Heat and Resistivity of Mild Steel*," by P. R. Pallister (April, 1957).

NEWS OF MEMBERS

Mr. **R. S. Bleckly** has been appointed a Director of the Lancashire Steel Corporation Ltd.

Mr. **T. Dennison** has resigned from the British Iron and Steel Federation to take up an appointment with G.K.N. (Group Services) Ltd., Cardiff.

Mr. **Arthur Dorman** (*Past-President*) has retired from the Board of Dorman Long and Co., Ltd.

Mr. **T. E. Downs** has been appointed a Director of Midland Rollmakers Ltd., C. Akrill Ltd., and Thomas Perry Ltd.

Mr. **W. Gillies** has been elected a Director of the Lanarkshire Steel Co., Ltd.

Mr. **J. Guthrie** has been appointed a Special Director of Colvilles Ltd.

Mr. **A. P. Hague** has retired from the Mond Group of Companies.

Mr. **T. H. Hirsche** has been promoted from Chief Metallurgist to be General Works Manager of the Union Steel Corporation (of South Africa) Ltd.

Mr. **R. S. James** has been appointed a Director of Midland Rollmakers Ltd., C. Akrill Ltd., and Thomas Perry Ltd.

Mr. **J. A. Kilby** has been appointed a Special Director of Colvilles Ltd.

Mr. **M. L. Melvill** has graduated from Cambridge University in metallurgy and is now a Technical Production Trainee with the Iron and Steel Corporation of South Africa.

Mr. **H. Morley** has been appointed Works Manager (Services) of Samuel Fox and Co., Ltd.

Mr. **J. E. Oram** has been appointed Managing Director of Wild-Barfield Electric Furnaces Ltd.

Mr. **J. B. Peat** has retired from the Board of Dorman Long and Co., Ltd.

Mr. **T. H. Stayman** has been appointed to the Board of Head Wrightson Iron and Steelworks Engineering Ltd.

Mr. **A. W. Taylor** has joined the Engineering Development Department of the Consolidated Mining and Smelting Company of Canada Ltd., Trail, B.C.

Mr. **H. Glynn Thomas** is now commencing erection of rolling mills in Avilés, Spain, on behalf of Davy and United Engineering Co., Ltd.

Mr. **D. J. Young** has joined the Board of the Steel Company of Wales Ltd.

Obituary

Mr. **Charles Ethelbert Wallin** (*elected* 1920), of Beaconsfield, on 20th January, 1957.

CONTRIBUTORS TO THE JOURNAL

J. W. Barton, B.ENG.(MET.)—Research Student, Metallurgy Department, Liverpool University. (*March issue*).

Mr. Barton was born in 1934 and educated at the Alsop High School, Liverpool, and the University of Liverpool. He was awarded the degree of B.Eng.(Metallurgy) in 1955, and is now a research student in the Department of Metallurgy. He has been assisted by grants from the Andrew Carnegie Scholarship Fund.

R. N. Dale, A.M.I.MECH.E.—New Work Engineer, Steel Company of Wales Ltd.

Mr. Dale received his technical training at the Glamorgan Technical College and, after serving in the Royal Engineers, joined the Steel Company of Wales Ltd. in 1948 as Planned Maintenance Engineer for the Abbey Works. In 1953 he was appointed Mechanical Development Engineer in charge of engineering improvements for steel plant and mills. Since March, 1956, he has been New Work Engineer for steelplant and hot mills.

R. N. Dale

J. O. Edström

G. D. Jordan

F. Moore

J. O. Edström—Research Metallurgist, Jernkontoret.

John Olof Edström was born in Stockholm in 1926, and graduated as metallurgical engineer from the Royal Institute of Technology there in 1950. From 1950 to 1953 he was research assistant to Professor M. Wiberg at the Institute, and received the degree of Licentiate of Technology (Lic. Tech.) in 1953, when he took up his present position. He was granted a year's leave of absence by Jernkontoret in 1954 to carry out research at the University of Minnesota, with fellowships from the Sweden–America Foundation and from Jernkontoret.

J. Halling, B.SC.(ENG.)—Lecturer in Mechanical Engineering, University of Liverpool. (*March issue*).

After service in H.M. Forces as a technical instructor from 1941 to 1946, Mr. Halling entered the Imperial College of Science and Technology; he graduated in 1948 in mechanical engineering with first-class honours. From 1948 to 1950 he was a member of the Scientific Civil Service on the staff of the Military College of Science, and in 1950 returned to Imperial College with a research fellowship to study rolling friction. Mr. Halling was appointed to his present position in 1952.

G. D. Jordan, M.ENG., A.M.I.PLANT E., A.M.I.MECH.E.—United Steel Companies Ltd., Department of Operational Research and Cybernetics. (*March issue*).

Mr. Jordan was born in 1925 and educated at King Edward VII School, Sheffield, and Sheffield University, graduating in mechanical engineering in 1944. After serving in the Royal Navy, he joined Samuel Fox and Co., Ltd., in 1947 as Technical Assistant to the Chief Engineer; subsequently he was appointed Lubricating Engineer. He transferred to the newly formed Department of Operational Research and Cybernetics of the United Steel Companies Ltd. on its formation in 1956. Mr. Jordan obtained the degree of M.Eng. in 1953 through the Postgraduate School of Applied Mechanics of Sheffield University in 1953. In the same year he was awarded a James Clayton Fellowship by the Institution of Mechanical Engineers, and toured the U.S.A. and Canada.

F. Moore—Deputy Mechanical Maintenance Superintendent, Steel, Peech and Tozer, Sheffield. (*March issue*).

Mr. Moore was educated at Scunthorpe Central School, and received his engineering training at the Frodingham Iron and Steel Co., Ltd. (now the Appleby–Frodingham Steel Company), where he worked for 18 years. After four years with the Power-Gas Corporation Ltd., Stockton-on-Tees, as a resident engineer, Mr. Moore spent two years as Assistant Chief Engineer at the Barrow Steel Works of the Ministry of Supply. In 1946 he joined Steel, Peech and Tozer as Maintenance Engineer at the Ickles Works, and was appointed Engineer for New Construction in 1950; he was promoted to his present position in 1953.

C. E. H. Morris, B.A., A.M.I.MECH.E.—Senior New Work Engineer, Steel Company of Wales Ltd.

C. E. H. Morris

Mr. Morris, who was born in 1926, was educated at Rugby School and Cambridge University, where he obtained his B.A. in the Mechanical Sciences Tripos. After service with the Royal Navy, he joined the Steel Company of Wales Ltd. (Steel Division) in 1949. He was at first engaged on the starting up of new rolling mills, and then became Technical Assistant successively to the Mills Superintendent and the Chief Engineer. He was awarded a Clayton Fellowship in 1952. After two years as Works Engineer (Rolling Mills), Mr. Morris was appointed to his present position, and made responsible for development of steelmaking plant and rolling mills.

H. W. A. Waring, C.M.G., A.C.A.—Managing Director, Brymbo Steel Works Ltd. and Director of Guest, Keen Iron and Steel Co., Ltd.

Mr. Waring was born in 1906 and was educated at Christ's Hospital. He qualified as a chartered accountant in 1929 and was resident on the Continent in Berlin, Hamburg, and Oslo until the outbreak of war. He joined the staff of the British Consulate in Oslo in 1939 and, after the occupation of Norway, was a member of the staff of the British Embassy (then a Legation) in Stockholm until 1945. During this period Mr. Waring was concerned with Sir George Binney in the purchase and the blockade running of iron and steel products, machine parts, ball-bearings, etc. from Sweden to the U.K. From 1943 onwards he was Ministry of Supply and Ministry of Economic Warfare representative. In 1944–45 he negotiated jointly with the Americans an agreement with Sweden stopping the export of ball-bearings to Germany. For his war-time services he was awarded the C.M.G. in 1945. Subsequently he was in Germany as a member of the Control Commission and, in his capacity as Deputy Director General of Metallurgy, he formed the first post-war German steel organization, then called the Verwaltungsamt für Stahl und Eisen. Later he was in charge of basic industries and finally became Deputy Chief of the Industry Division.

In 1947 he was appointed Secretary of Guest, Keen Baldwins Iron and Steel Co., Ltd. (now Guest Keen Iron and Steel Co., Ltd.) and remained there until 1951, when he joined the Economic Commission for Europe as Director of its Industry Division, where he was directly responsible for the International Committees on steel, coal, electric power, and housing. In 1956, Mr. Waring re-joined the Guest Keen and Nettlefolds Group of Companies and was made a Director of Brymbo Steel Works Ltd. and Guest, Keen Iron and Steel Co., Ltd. As from 1st January, 1957 he was appointed Managing Director of Brymbo Steel Works Limited.

Mr. Waring speaks several languages and has travelled very widely in Europe and elsewhere. In 1952 he attended the plenary session of the Economic Commission for Asia and the Far East in Rangoon. He has twice visited the U.S.S.R., on the second occasion with the steel experts who went to the Ukraine in 1955. He attended the first Latin American steel meeting, sponsored by the United Nations in Bogota, Colombia, in 1952 and has recently returned from a prolonged visit to Latin America, where he attended, *inter alia*, the second steel meeting, held in Sao Paulo in the autumn of 1956.

H. W. A. Waring

T. Williams

R. O. Williams, M.S., PH.D.—Research Department, Cincinnatti Milling Machine Company, Cincinnatti, Ohio, U.S.A. (*March issue*).

Robin O. Williams, who is 29, graduated from the University of Tennessee in 1948 with a B.S. degree in chemical engineering. He worked for three years in the Metallurgy Division of the Oak Ridge National Laboratory, during which time he gained the M.S. degree of the University of Tennessee. The three years from 1951 to 1954 he spent at the Carnegie Institute of Technology, Pittsburgh, Pa., working for his Ph.D. For the next two years he was with the General Electric Research Laboratory in Schenectady, N.Y., and he joined his present company in 1956. Dr. Williams has carried out research principally in the fields of preferred orientation and precipitation hardening, and is at present engaged on an investigation into plastic behaviour.

T. Williams, F.I.M.—Armament Research and Development Establishment, Ministry of Supply, Fort Halstead, Kent.

Mr. Williams was educated at Shooters Hill Grammar School, Woolwich, and at Nottingham and District Technical College. He joined the A.R.D.E. (then known as the Research Department, Woolwich) in 1935, and is now a Senior Experimental Officer in the Ferrous Metallurgy section of the Materials Division of the Fort Halstead Establishment.

INSTITUTE OF METALS

Metal Physics of Corrosion

The Metal Physics Committee of The Institute of Metals is holding a discussion on "The Metal Physics of Corrosion and Oxidation" at Church House, Great Smith Street, London, S.W.1, at 2.30 p.m. on 30th April, in connection with the Institute's Spring Meeting. The discussion will be opened by Dr. O. Kubaschewski (National Physical Laboratory) and Dr. C. Edeleanu (Tube Investments Research Laboratories). Members of The Iron and Steel Institute are invited to attend the meeting; no tickets are required.

BRITISH NUCLEAR ENERGY CONFERENCE

Institute of Metals

During the Institute of Metals Spring Meeting, the discussion on the morning of 1st May will come under the programme of the British Nuclear Energy Conference. At this meeting, which will be held at Church House, Westminster, beginning at 10 a.m., the following papers, all of which will be printed before the meeting in the *Journal of The Institute of Metals*, will be presented: "The Development of Niobium", by A. B. McIntosh; "The Purification of Niobium by Sintering", by W. G. O'Driscoll and G. L. Miller; "The Production and Fabrication of Massive Niobium Metals", by L. R. Williams; "The Physical and Mechanical Properties of Niobium", by C. R. Tottle; and "The Melting Point of Niobium", by T. H. Schofield. No tickets are required for the meeting.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Open Days at Swansea

The British Iron and Steel Research Association will hold two Open Days at the Sketty Hall Laboratories, Swansea, on Wednesday and Friday, 19th and 21st June, 1957, for representatives of member firms and users of steel sheet and strip.

The Sketty Hall Laboratories are devoted to research into problems concerning steel coatings and methods of surface preparation. The Open Days will provide the opportunity for showing improvements in existing coating methods, together with developments in the use of new coating materials. Demonstrations will be given on the recently installed experimental line for the production of PVC–bonded steel strip and on the differential roller tinning pilot plant now being built. Further details will be announced in the *Journal* later.

Professor **G. Wesley Austin** has accepted an engagement as Consulting Supervisor to the Metallurgy Division of B.I.S.R.A. He will be responsible for the general supervision of the metallurgical research programme on behalf of the Metallurgy (General) Panel of the Association.

CORRIGENDA

The following alterations should be made to the paper "Obervations on the Mechanical Behaviour of Heat-treated Steel at High Hardness Levels," by N. H. Polakowski (*J. Iron Steel Inst.*, 1957, January, vol. 185, pp. 67–74):

Fig. 5: "Q. + 1400°" on abscissa should read "Q. + 400°"

Fig. 7.—Delete bars on σ and ϵ on abscissa; formula should read "$n = \log(\sigma/a)/\log \epsilon$"

Fig. 9.—Centre right-hand graph should be (*d*); graph (*e*) refers to position *C*, not *A*; in graph (*f*) "$\sim$ 700° C" should be "$\sim$ 400° C"

DIARY

1st Apr.—Institute of British Foundrymen (Sheffield and District Branch)—Annual General Meeting, followed by film "Flow of Metal into Moulds"—Sheffield College of Commerce and Technology, Pond Street, Sheffield 1, 7 p.m.

2nd Apr.—British Nuclear Energy Conference—"The Aqueous Homogeneous Reactor," by R. Hurst, I. Wells, and D. Newby—Royal Institution, Albemarle Street, London, W.1, 5.30 p.m.

2nd Apr.—Institute of Metals (Oxford Local Section)—Annual General Meeting, followed by "Fatigue," by Dr. N. Thompson—Cadena Cafe, Cornmarket Street, Oxford, 7 p.m.

3rd Apr.—The Iron and Steel Institute (Engineers Group)—"Lubrication in Iron and Steelworks," by H. Jones and G. D. Jordan—4 Grosvenor Gardens, London, S.W.1, 10.30 p.m.

3rd Apr.—Society of Chemical Industry (Corrosion Group)—"The Protection of Structural Steelwork against Corrosion," by J. C. Hudson (joint meeting with South Wales Section)—Technical College, Newport, Mon., 7 p.m.

4th Apr.—Institute of Metal Finishing—"Fuel Economies in the Metal Finishing Industry," by G. Gill—Engineers' Club Albert Square, Manchester, 7.30 p.m.

4th Apr.—Leeds Metallurgical Society—"Fatigue in Metals," by P. J. E. Forsyth—Large Chemistry Lecture Theatre, The University, Leeds, 7.15 p.m.

4th–6th Apr.—Institute of British Foundrymen—Training Course, Harrogate.

8th Apr.—Sheffield Society of Engineers and Metallurgists—Film Night—Engineering Lecture Theatre, St. George's Square, Sheffield, 7.30 p.m.

8th–12th Apr.—Second International Congress of Surface Activity—London.

9th Apr.—East Midlands Metallurgical Society—"Nickel-base Alloys for High-temperature Service," by A. W. Franklin—Nottingham and District Technical College, 7.30 p.m.

9th–13th Apr.—Institute of Metal Finishing—Spring Meeting—Brighton.

10th Apr.—Institution of Mechanical Engineers—Discussion on Standardization of Lubricants—1 Birdcage Walk, London, S.W.1, 6.45 p.m.

11th Apr.—Liverpool Metallurgical Society—"Vacuum Techniques in Metallurgy," by M. Harper, followed by Annual General Meeting—9 The Temple, Dale Street, Liverpool, 7 p.m.

11th Apr.—Staffordshire Iron and Steel Institute—"Engineering Problems Encountered in Developments at Bilston Blast Furnace and Open Hearth Plants," by D. C. Hendry—Star and Garter Royal Hotel, Wolverhampton, 7.30 p.m.

12th Apr.—North East Coast Institution of Engineers and Shipbuilders—"Failure of Welded Steel Structures," by T. W. Bushell—Mining Institute, Newcastle upon Tyne, 6.15 p.m.

12th Apr.—West of Scotland Iron and Steel Institute—Annual General Meeting; "Continuous Casting," by J. R. Rippon—38 Elmbank Crescent, Glasgow, 6.45 p.m.

17th Apr.—Institute of British Foundrymen (London Branch)—Annual General Meeting, followed by film "Flow of Metal into Moulds"—Constitutional Club, Northumberland Avenue, London, W.C.2, 7 p.m.

17th Apr.—Newport Metallurgical Society—Annual Meeting—Whitehead Iron and Steel Institute, Newport, 7 p.m.

24th Apr.—Institute of Fuel—Presidential Address—Institution of Civil Engineers, Great George Street, London, S.W.1, 5.30 p.m.

25th Apr.—Institution of Fuel—Annual General Meeting and Luncheon.

25th Apr.—Institution of Mechanical Engineers—Discussion on the Removal of External Deposits on Boilers—1 Birdcage Walk, London, S.W.1, 6.45 p.m.

26th Apr.—Lincolnshire Iron and Steel Institute—Annual Dinner—

26th Apr.—Sheffield Society of Engineers and Metallurgists—Biennial Dinner—Royal Victoria Station Hotel, Sheffield, 7.30 p.m.

29th Apr.–4th May—Institute of Metals—Joint Spring Meeting with Associazione Italiana di Metallurgia, Société Suisse des Constructeurs de Machines, and Schweiz. Verband für die Materialprüfungen der Technik—Royal Institution, Albemarle Street, London, W.1 (29th Apr.) and Church House, Great Smith Street, London, S.W.1 (30th Apr.–4th May).

30th Apr.—Institute of Metals—Discussion on "The Metal Physics of Corrosion and Oxidation"—Church House, Westminster, London, S.W.1, 2.30 p.m.

30th Apr.–2nd May.—Institution of Mechanical Engineers—Conference on the Properties of Materials at High Rates of Strain—1 Birdcage Walk, London, S.W.1.

TRANSLATION SERVICE

(The previous announcement was made in the March, 1957, issue of the Journal, p. 412).

Translations Available

No. 519 (Russian). T. P. Kolesnikova and A. M. Samarin: "Influence of Manganese, Chromium and Vanadium upon the Surface Tension of Molten Iron". (*Izvestiya Akademii Nauk S.S.S.R., O.T.N.*, 1956, No. 5, May, pp. 63–69.)

No. 520 (German). A. Schrader: "Structural Changes in Ferritic and Austenitic Special Steels due to Prolonged Stressing at High Temperatures". (*Revue Universelle des Mines*, 1956, vol. 12, Oct., pp. 537–542; discussion, p. 543.)

No. 521 (Russian). G. G. Oreshkin: "Experimental Running of Blast-Furnace with an Unconventional System of Cooling the Shaft and Bosh". (*Metallurg*, 1956, No. 3, pp. 1–7.)

No. 522 (German). K. Giesdorf: "Operating Experiences with Electric Main Drives of Modern Reversing Mills". (*Stahl und Eisen*, 1956, vol. 76, Sept. 20, pp. 1231–1246.)

Translations in Course of Preparation

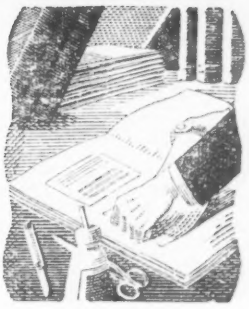
(Russian). Yu. A. Geller: "Determination of the Mechanical Properties of Tool Steels." (*Zavodskaya Laboratoriya*, 1955, vol. 21, No. 5, pp. 594–601).

(German). F. Harders, H. Knüppel and K. Brotzmann: "The Industrial Large-Scale Treatment of Steel Melts under Reduced Pressure". (*Stahl und Eisen*, 1956, vol. 76, Dec. 27, pp. 1721–1728.)

(German). E. Wilms: "What the Rolling Mill Engineer Requires of the Electrical and Mechanical Part of Single-Stand Reversing Mills". (*Stahl und Eisen*, 1956, vol. 76, Feb. 23, pp. 185–192.)

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects



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MINERAL RESOURCES

Study and Mineralogical Analysis of the Lorena Iron Ores. their Composition and their Capacity for Enrichment. M, Deudon. (*Inst. Hierro Acero*, 1956, **9**, July, 815–822. Special Number). [In Spanish]. An account is given of a study by IRSID of the Lorena ores by standard and original techniques, which has resulted in the indentification of several silicates and carbonates and a better understanding of the nature of the oolites. This study has enabled conditions of benefication to be clarified e.g. crushing size for physical tests and the mineral which it is desired to concentrate, and that enrichment is greater the less chlorites are present.

Physical Properties of the Sierra Menera and Vivero Iron Ores, the Carbonate of the Orconera Deposits and of their Sintering Charges. J. A. Boned Sopena. (*Inst. Hierro Acero*, 1956, **9**, July, 841–857. Special Number). [In Spanish]. The results of sieve analysis, porosity, wet and dry permeability, thermal behaviour of sintering charges made up of these ores were studied and a good gas permeability was found to depend on a good caking ability, good bond strength, and a short fusion period. All three ores were shown to be lacking in one or other of these qualities. The permeability during sintering has been improved by adding quicklime, but the results of these trials are reported elsewhere. (12 references).—P. S.

Canadian Iron Ore in 1955. (*Metal Bull.* 1956, Sept. 18, 13–15, 27). Statistical, with map.

Deposits of Iron Ore in Victoria. (*Chem. Eng. Min. Rev.*, 1956, **48**, June 11, 272).

The Iron and Titanium Ores of New Zealand: Occurrence, Composition, Attempts to Use and Status today with Special Reference to Ironsands. W. R. B. Martin. (*New Zealand Eng.*, 1955, **10**, Oct. 15, 317–336). The occurrence, type, composition and estimated quantity of New Zealand iron and titanium ore deposits are summarized. The major deposits are Titanomagnetite (60% Fe and 5% Ti), 800–1000 million tons; Ilmenites ("black" sand, 33% Fe and 27% Ti), 55 million tons; and Limonites (Orekaha ore, 40% Fe), 9·5 million tons. The availability of coal for electric furnace smelting is discussed and access to the ore deposits is described. Suitable methods of ore preparation and agglomeration are dealt with and an analysis is made of the failure of earlier attempts to smelt the ores economically. The 1949 proposals for electric smelting of iron sands are described in detail and the results of pilot plant experiments are reported. It is concluded that the economically workable ironsands and ilmenites could be mined and handled with ease and could be smelted by electric furnaces. (51 references).

ORES—MINING AND TREATMENT

The Ore Industry in Venezuela. (*Bol. Min. Indust.*, 1956, **35**, Apr., 187). Brief review of the iron ore output from Venezuela. The two U.S.A. controlled mining companies produced 5,420,000 tons in 1954 an increase of 135% over 1953. An output of 8 million tons is projected for 1955.

Preliminary Mineral-Dressing Investigation of East Texas Brown Iron Ores. M. M. Fine, D. W. Frommer and W. M. Dressel. (*U.S. Bur. Mines, Rep. Invest.*, 5252, 1956, July, pp. 10). Various fractions, concentrates, and roasting and magnetic separation tests are summarized.

Exploration and Utilization Studies, John Day Chromites, Oregon. R. J. Hundhausen, L. H. Banning, H. M. Harris and H. J. Kelly. (*U.S. Bur. Mines, Rep. Invest.*, 5238, 1956, July, pp. 67). Smelting tests are summarized.

A Rapid Method for Determining the Basicity of Iron Ore. A. Jeczalik. (*Hutnik*, 1955, **22**, (12), 445–448). The method consists of determining the combined (CaO + MgO) content without separating the constituents. A 66% reduction on the time necessary to calculate the basicity is quoted.

Study of the Concentration of Titano-Iron Ore, Mainly of Roasting and Magnetic Separation. H. Nakayama, T. Suzuki and T. Okubo. (*Tokyo Univ. Fac. Eng. Annual Report* 1955, 223–240). Experiments on Philippines ore are described.

The Electrical Resistivity of Some Oxide and Sulphide Minerals. D. S. Parasnis. (*Jernkontorets Ann.*, 1956, **140**, (7), 494–511). [In Swedish]. The four-point method—similar to that used by geophysicists—was employed in the investigations. Local variations in resistivity in the specimen, such as cracks and inhomogeneities, can easily be checked by moving the four electrodes which are in a straight line to another area of the surface. Tests showed that mineral resistivity varies in two ways: a local variation of ± 30% or more around the mean value, and variations between different specimens of the same mineral which are likely to be tenfold or more in magnitude.—G. G. K.

Equilibrium Considerations in the Roasting of Metallic Sulfides. H. H. Kellogg. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956 **8**, Aug., Section 1, 1105–1111). The author reviews the chemistry of sulphide roasting, showing those aspects of performance which can be predicted from considerations of thermodynamic equilibrium. It is concluded that equilibrium calculations can serve as a yardstick for prediction of roaster-gas composition and sulphate formation in the calcine for fluid-bed roasting practice. A method of calculation, combining equilibrium and stoichiometric factors, is outlined and illustrated by an example from the roasting of copper-iron sulphides.—G. F.

Oxidizing Roasting of Ore Concentrates. P. F. Snezhko. (*Stal'*, 1956, (4), 327–330). [In Russian]. Good results were obtained by using rotating kilns for roasting titanomagnetite and wolframite concentrates. Operating data are presented.

Flocculation of Mineral Suspensions with Coprecipitated Polyelectrolytes. M. E. Wadsworth and J. B. Cutler. (*Min. Eng.*, 1956, **8**, Aug., 830–833). Haematite suspensions are studied.

Sintering Iron Ores and Concentrates at Extaca. R. L. Bennett, R. E. Hagen, and M. V. Mielke. (*Amer. Inst. Min. Met. Eng.*, 1956. *Preprint*). Both iron ore fines and magnetite concentrates from taconite are agglomerated at the Extaca plant of United States Steel Corporation. Details are given of the development and operation of the process, and the sinter-plant equipment is described.—G. F.

Possible Ways of Raising Sinter Plant Performance. B. Weilandt and W. Storsberg. (*Stahl u. Eisen*, 1956, **76**, July 12, 870–878). Quantities affecting plant performance are reviewed. The authors refer to the preparation of fine ores for sintering and discuss both the strength of the particles and their behaviour during the mixing process. They also discuss the effects of additives, the dependence of performance on the method of preparing the fine ore, and the particle structure of sinter mixes.

Permeability of Sinter-plant Feed. M. O. Holowaty and J. F. Elliott. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm.*, 1955, **14**, 26–38). The authors describe a laboratory study of the influence of ore mixtures, method of mixing, moisture content, and proportion of return fines on the permeability of several types of raw feed. The results show the necessity for control of the flow and physical character of the fines, and of the weights, proportions, moisture content, and mixing of the feed.—G. F.

Gravimetric Blending and Controls in Sinter Plant Operation. T. R. Zatkovich and B. E. Hamlett. (*Blast Furn. Steel Plant*, 1956, **44**, Sept., 1040–1042). The merits of feeder tables and constant weight belt type feeders for use on sinter plants are discussed.—B. G. B.

Investigations to Determine the Optimum Moisture and Fuel Contents of Fine Ore Mixtures for Sintering. H. Kosmider, E. Bertram, and H. Schenck. (*Stahl u. Eisen*, 1956, **76**, July 12, 858–870). The experimental installation used, and the determination of permeability to air made on it, are both described. Ores are classified according to sintering quality. The effects of admixture with lime, dolomite, and slate dust, the influence of particle size, the rate of oxidation, and the application to sinter mixes of results obtained with particular ores, are among the subjects discussed.

Optimal Conditions for Sintering Krivoi Rog Ores. N. Z. Plotkin. (*Stal'*, 1956, (4), 295–302). [In Russian]. A laboratory scale apparatus is described with the aid of which optimal conditions as regards moisture, percentage return fines and other factors were studied. Results of three series of experiments are presented.—S. K.

FUEL—PREPARATION, PROPERTIES AND USES

A Mixing Rule for Laminar Flame Speed. D. B. Spalding. (*Fuel*, 1956, **35**, July, 347–351). A simple mixing rule is given which may be used to predict the laminar flame speed of a mixture of two combustible gases when the flame speeds of the components are known as a function of temperature.

Flame Speeds of Mixtures Containing Several Combustible Components or a Known Quantity of Diluent. D. G. Martin. (*Fuel*, 1956, **35**, July, 352–358). A comparison is made between the predictions of a mixing rule (see previous abstract) and experimental results. This rule is shown to be capable of predicting accurately the manner and magnitude of the variation of flame speed.—B. G. B.

Petrologic Methods for Application to Solid Fuels of the Future. J. M. Schopf. (*Min. Eng.*, 1956, **8**, June, 629–639). A survey is made of the information which can be obtained from petrological examination of coal and its classification, and methods of obtaining these data, including the Whipple disc technique. Applications for geological, mining and industrial purposes are outlined. Petrological studies will become more important, in view of the assessment of coal for the chemical industry, the proving of reserves, the importance of properties in making metallurgical coke and blending coals, and the depletion of high-quality coal sources. (45 references).—K. E. J.

Design of a Vibrating Screen for Testing Coke. Ch. G. Thibaut and P. Vigneron. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, **13**, No. 7, 1397–1400). A sieving machine with a surface area of 1·5 m² powered by a 3 H.P. motor and which has been found very satisfactory for sieving coke is described.–B. G. B.

Developments in Coal Stockpiling and Reclaiming. (*Mech. Handling*, 1956, **43**, Oct., 617–619). A "twin-power" scraper is described.

Mixed Commission for Coke Ovens, Gas Works, Mines and Steel Works. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, **13**, No. 7, 1375–1381). I. The possible addition of coke dust to coal prior to coking is discussed. II. A description is given of a 400 kgm test furnace for carrying out coke making research work on a pilot plant scale.—B. G. B.

Pilot-Scale Coke Ovens—Development and Operation. R. T. Eddinger and J. Mitchell. (*Indust. Heating*, 1956, **23**, July, 1440–1442). A pilot scale coke oven (dimensions unspecified) is described and conditions of operation for simulation of industrial coking practice are given. Preliminary results indicate that plant oven carbonization practice can be predicted by use of the test oven.—A. D. H.

Mechanical Charging of Coke Ovens. L. S. Freebury. (*Coke Gas*, 1956, **18**, Sept., 353–354). The construction and use of a turntable lorry for oven charging is described. The advantages of this type of charger are given.—R. F. P.

Influence of Temperature on Mechanical Strength of Coke. J. Varga Jr., and H. W. Lownie Jr. (*Amer. Found. Soc. Preprint*, 1956, No. 27). The development of a tumbler test for determining the mechanical strength of coke at elevated temperatures is described and some results obtained with the apparatus are presented. The main conclusion drawn from the work is that the mechanical strength of coke at room temperature gives no indication of its strength at the temperatures encountered in cupola operation.—B. C. W.

Gas and Coke from Non-Caking Fuels. (*Coke Gas*, 1956, **18**, Sept., 347–352). A review is given of research work in Germany and Australia on the use of lower rank coal for coking. Some success has been achieved and further progress can be expected . References to similar work in Britain are given.—R. F. P.

Study of the Incorporation of Lime in Coke Pastes. E. Burstlein. (*Centre Doc. Sidér Circ. Inform. Tech.* 1956, **13**, No. 7, 1383–1388). The drying of moist coke dust by addition of quicklime is described. The results indicate that rapid dehydration can be obtained and the coke dust can then readily be screened.—B. G. B.

Structural Changes Occurring in Coal During Coking. M. F. Kessler and V. Večeříková. (*Paliva*, 1956, **36**, (6), 192–199). [In Czech]. Structural changes occurring in coking were studied by means of X-rays, and related to changes in the (002) carbon lattice spacing. The structural changes during carbonization are mainly the splitting of C–O, C–N, and C–H bonds in the aliphatic side-chains, and the subsequent aromatization, which is associated with the characteristic dilatation of the lattice. The relation of this dilatation to coke quality is discussed. Earlier work is critically reviewed.—P. F.

Appreciation of the Physical Quality of Coke in Eastern Germany. Ch. G. Thibaut. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, **13**, No. 7 1389–1392). A comparison of Ilsede and Micum methods of measuring coke strength is made; the former being used in Germany and the latter in France.

The Decomposition of Coal in Relation to the Plastic Layer. H. R. Brown. (*Coke Gas*, 1956, **18**, Oct., 390–392). The results of research on the coking process are discussed. Softening temperature was measured with a Gieseler plastometer and weight loss with a differential thermogravimetric balance.

Comparative Study of the Reactivity of Cokes and their Internal Surface. M. Bastick, J. Bastick, M. Moutach, and H. Guérin. (*Compt. Rend.*, 1955, **240,** June 27, 2524–2526). Cokes with initially the same surface area behave differently in carbon dioxide and steam. Their reactivity although dependent on the surface area is not proportional to it. The measured surface area is not the surface available to molecules of CO_2 and H_2O. Two phases of gasification are considered to occur which are related to the pore diameters. Hence a determination of these diameters as function of the pore area is likely to throw useful light on the subject. The reactivity tests were carried out between 900° and 1100° C.—G. E. D.

Experimental Studies of Gasification of Powdered Coal in Fluidized Bed. S. Yagi, D. Kunii and H. Masumoto. (*Tokyo Univ. Fac. Eng. Annual Report*, 1955, 153–156). A laboratory study.

Combustion Systems and Burners. H. W. Schramm (*Indust. Heating*, 1956, **23,** June, 1184–1194, 1330; July, 1396–1408). Equipment and methods for proportioning, delivery and combustion of gas and air are explained and methods for control of atmospheric and high pressure combustion are considered in detail.—A. D. H.

AIR POLLUTION AND SMOKE

Effects of Velocity and Temperature of Discharge on the Shape of Smoke Plumes from a Funnel or Chimney. Experiments in a Wind Tunnel. L. W. Bryant and C. F. Cowdrey. (*Proc. Inst. Mech. Eng.*, 1955, **169,** (23), 371–400). The authors report an experimental investigation of the flow of smoke plumes by model tests and present a theoretical extrapolation to determine the behaviour at greater distances from the orifice of issue. The effect of washing on the effluent path is examined and it is concluded that washing is effective in reducing the ground-level sulphur dioxide concentration only under certain conditions of wind speed, orifice diameter and effluent velocity.—A. W. Mcc.

Cleaning of Open Hearth Stack Gases. L. Silverman. (*Indust. Heating*, 1956, **23,** Jan., 96–102; Feb., 322–326, 354). A filtration method using a continuous filter of slag wool which is afterwards washed and dried, is described, and data are presented on its performance.—A. D. H.

Emissions from Cupolas. F. M. Shaw. (*Found. Trade J.*, 1956, **101,** Aug. 30, 217–228). A comprehensive discussion is given of the problem of dust, fume, and smoke emission from cupolas and of the various types of dust collectors now available. Particular attention is paid to the spray- and baffle-type collectors. (30 refs.).—B. C. W.

West Gas Cleaning using a Venturi Jet. A. Udrycki. (*Hutnik*, 1955, **22,** (12), 448–453). The principles of the method are discussed and simple mathematical calculations given to explain the mechanism and factors affecting the efficiency of the cleaning process. Pre-cooling the incoming gas is shown to be beneficial, and a temperature not exceeding 100° C is suggested.—W. E. & A. P. M.

The Treatment of Corrosive Fumes. II. Fumes from Pickling Plants. F. F. Jaray. (*Corrosion Prevention and Control*, 1955, **2,** Sept., 43–45, 55). The author discusses the problems arising when dealing with fumes resulting from pickling processes. Two typical methods (fume scrubbing and chemical neutralization) are described which illustrate the wide field of fume treatment.—L. E. W.

TEMPERATURE MEASUREMENT AND CONTROL

Molten Metal Pyrometer. (*Engineering*, 1956, **182,** Aug. 10, 182). A base metal couple reading up to 1100° C or a noble metal couple reading up to 1550° can be included.

Temperature Control for Steel Melts and Casting Operations. K. Guthmann. (*Radex Rundschau*, 1955, (7), Nov., 577–591). Immersion, colour, and radiation pyrometers are discussed and their applications for various foundry operations are considered. A combined method of pyrometry is advocated for ensuring a high degree of accuracy in quality control.

REFRACTORY MATERIALS

All-Union Meeting of Refractory Workers. D. A. Smolyarenko. (*Stal'*, 1956, (4), 361–362). [In Russian]. Reports and discussion at a meeting of representatives of the research and production sides of the refractory industry of the U.S.S.R. are outlined. The meeting was held in Stalino in Dec. 1955.—S. K.

An X-ray Study of the Inversion and Thermal Expansion of Cristobalite. W. Johnson and K. W. Andrews. (*Trans. Brit. Ceram. Soc.*, 1956, **55,** Apr., 227–236). The $\alpha \rightleftharpoons \beta$ inversion in a sample of very pure cristobalite was examined by means of a high-temperature X-ray camera. The transformation occurs at 218 ± 2° C and there is a volume increase of 3·7%. The low temperature form is tetragonal and the high is cubic. The thermal expansions were also studied.

Studies on Unburnt Bricks. S. Nagai, K. Yoshizaki, S. Komatsu and Y. Niki. (*Tokyo Univ. Fac. Eng. Annual Rept.*, 1955, 91–94). Plibrico Super was investigated and compositions and properties of mixtures for plastic refractories are given in comparison.

Studies of Unburnt Refractories. S. Nagai, F. Tanemura, Z. Ota and M. Tsukino. (*Tokyo Univ. Fac. Eng. Annual Report* 1954, 159–162). Chromite magnesia bricks are studied with regard to moulding pressure, drying condition, grading, binders and texture changes during service.

Studies of Unburnt Refractories II. S. Nagai, Z. Ota, F. Tanemura and M. Tsukino. (*Tokyo Univ. Fac. Eng. Annual Report*, 1955, 75–78). Fireclay-base refractories of the Al_2O_3–SiO_2 system are considered. Tables of composition, shrinkage and compressive strength are given.

Studies on Special Refractories. S. Nagai, K. Yoshizaki, and S. Komatsu. (*Tokyo Univ. Fac. Eng. Annual Report*, 1954, 50–53, summary 246). A further report on magnesite–chromite using sea-water magnesia.

Rupture Modulus of Spanish Refractory Materials. V. Gomez Garcia. (*Inst Hierro Acero*, 1956, **9,** May, 543–547. Special Number). [In Spanish]. The rupture moduli for an average of five tests on each of 93 samples of silica (93–97% SiO_2), alumino-silica (20–35% Al_2O_3), and high alumina (36–42%) refractories, and for each of 25 samples of magnesite (85–88% MgO) and chrome-magnesite (30–35% Cr_2O_3) refractories were determined by a standard ASTM method. The corresponding values ranged from 12–50, 20–147, 41–200, 57–167, and 16–158 kg/cm² respectively. These results are related to the manufacturing method; they give distribution curves whose maxima could be used as standards.—P. S.

Studies of Chromite-Magnesia Refractories Using Sea-water Magnesia. The Effects of Lime Included on Service. S. Nagai, Z. Ota, F. Tanemura, and K. Suzuki. (*Tokyo Univ. Fac. Eng. Annual Report* 1954, 45–53, summary 245–246). Lime initially present and that absorbed during service are distinguished as primary and secondary. The effect of secondary lime on service in rotary kilns is investigated.

Oriented Periklase Extension in Used Refractory Basic Bricks. W. Zednicek. (*Radex-Rundschau*, 1956, Mar., 80–86). Microscopical examination of used magnesite and chrome–magnesite bricks from O.H. furnaces shows elongation of periclase. Evidence is presented that this is a reorientation process of the cube face towards the heated side.

Enquiry on Ladle Bricks. M. Thiault. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, **13,** No. 8, 1599–1612). A survey of the performance of refractory bricks in ladles at 45 steelworks is reported.—B. G. B.

Developments in the Manufacture and Use of Vermiculite High Temperature Insulation. J. Hitner. (*Amer. Ceram. Soc. Bull.*, 1956, **35,** April, 147–150). A pilot plant study of vermiculite high-temperature insulation is described. Batch compositions, forming methods, and physical properties of the fired brick are given.—D. L. C. P.

IRON AND STEEL—GENERAL

Metallurgical Trends in France. P. G. Bastien. (*Rev. Mét.* 1956, **53,** June, 11–21, Special No.). A short review of the development of the ferrous and non-ferrous industry of France is presented.—B. G. B.

[U.S.S.R. Iron and Steel] Fulfilling the Decisions of the Twentieth Party Congress. (*Stal'*, 1956, (4), 291–292). [In Russian]. The developments required from the Soviet iron and steel industry in the 6th five year plan are outlined. Among measures envisaged is the production of 15–20 million tons per year of steel in Siberia and the increased use of sinter (80% of burden by 1960), all of it self-fluxing after 1957. Large blast furnaces will be built, including two of 2000 m³ useful volume. Greater use is to be made of oxygen for steel production, and O.H. furnaces of 500 tons capacity are to be

used. Rolling speeds are to be increased and new rolling and tube mills are to be installed.—S. K.

Austrian Iron Resources. C.-M. Goussot. (*Génie Civil*, 1956, **133,** Sep. 15, 339–341). Mines and steelworks and their equipment and output are reviewed.

Introduction of New Methods in Ferrous Metallurgy. (*Stal'*, 1955, (12), 1059–1062). [In Russian]. After a brief account of recent successes and failures in the Soviet iron and steel industry, improvements in methods and equipment planned for 1956 are outlined. These include conversion of blast-furnace practice to 100% sinter and prepared-ore operation, detailed design of larger blast and O.H. furnaces, provision and use of more tonnage oxygen, increased production of an increased range of rolled products. Severe criticism is made of the complacency of some Soviet authorities and their failure to make use of published foreign experience. Details are given of failures by individual works, the Ministry or scientists to ensure the successful completion of production scale experiments and the introduction of new and improved methods.

Inland Steel's Program of Expansion to Increase Capacity by 1959 to 6,000,000 tons. C. Longenecker. (*Blast Furn. Steel Plant*, 1956, **44,** Aug., 884–930). A comprehensive account of this American integrated steel works at Indiana Harbour, Lake Michigan is given; particular reference is made to future developments.—B. G. B.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Iron Operations of the Quebec Iron and Titanium Corporation. G. G. Hatch and N. H. Cuke. (*Trans. Canad. Inst. Min. Met.*, 1956, **59,** 359–362; *Canad. Min. Met. Bull.*, 1956, **49,** Sept., 619–622). The economic factors leading to the use of a process for reducing an ilmenite/haematite ore in electric furnaces is described. Titanium dioxide slag is produced and a high purity iron that has special applications in foundries and steel making. The high cost of furnace desulphurization has been reduced by using calcium cyanamid in the ladle. It is possible to reduce the sulphur content to 0·01%. Chemical analyses of the ore and iron produced are shown.

ISCOR Orders Africa's Largest Blast Furnace. (*Engineer Foundryman*, 1956, **21,** July, 38). Details of the construction of a blast furnace to be erected at Pretoria, S. Africa are given. The hearth diameter will be 25 ft.—A. D. H.

Reconstruction of the Foundations and Hearth of a Blast Furnace. P. Thierry. (*Mét. Constr. Mécan.* 1956, **88,** May, 439–449). A detailed account of the rebuilding of the hearth and foundation of a blast furnace without disturbing the stack and superstructure is given. A number of photographs showing the various stages of the reconstruction are reproduced.—B. G. B.

Modern European Hot Blast Changing Equipment. H. Jansen. (*Iron Steel Eng.* 1956, **33,** July, 137–143). Valve design and layout is described.

Topping Turboblowers for Blast Furnaces. E. O. Austermiller. (*Iron Steel Eng.*, 1956, **33,** Sept., 173–180). An account of two turboblowers serving three furnaces. Installation and split wind blowing are described. Owing to a shut-down it was possible to put them in simultaneously. Steam requirements and air outputs are given.

Hydraulic Packing for the Charge Distributor when Working at Elevated Pressure. D. A. Storozhik. (*Stal'*, 1956, (4), 367–368). [In Russian]. A mercury-water seal for the rotating distributor in blast furnaces working with high top pressure is described and its advantages over the dry seal are discussed.—S. K.

Acid (Blast Furnace) A Practice at Neuves-Maisons. M. Roulleau. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, No. 9, 1793–1812). This works is situated near to the siliceous iron ore deposits at Nancy and the results of acid blast furnace practice are described in detail. A number of full scale blast furnace trials carried out between 1949 and 1955 are reported. Changes in the CaO/Sio_2 ratio of 1·05 to 1·40 are included in these trials and changes is burden preparation and manganese recovery tests are also reported and discussed.

Low Fuel Rates with Coke-Anthracite Mixtures in 3-ft Blast Furnace. R. C. Buehl and M. B. Royer. (*J. Met.*, 1956, **8,** Apr., 432–438). A description is given of the 3 ft experimental blast furnace of the U.S. Bureau of Mines, and operating results are presented showing its successful use for the comparison of blast furnace ores and fuels. Anthracite has been satisfactorily substituted for part of the coke to the extent of 60% of the fuel requirement with certain prepared ores, giving lower fuel and higher production rates at constant blowing rate.—G. F.

Lignite Coke in Low-Shaft Blast-Furnace. G. Bruckner. (*J. Met.*, 1956, **8,** Sept., 1160–1161). Experiments on the low-shaft blast furnace at Maxhütte show that the furnace can operate successfully on 100% lignite high-temperature coke. Operating data are given.—G. F.

What Can Production–Function Analysis Do for the Metallurgical Industry. N. R. Gardner, J. B. Wolf, and A. J. Shaler. (*Microtecnic*, 1956, **10,** (2), 65–70). Examples are given to illustrate the meaning and uses of production-function analysis, and a detailed account is given of the development of a production function for the blast furnace.

The High-Pressure Operation of Blast-Furnaces at the Kuznets Combine. B. N. Zherebin, G. E. Kazarnovskiĭ, N. V. Krepÿshev, and V. M. Minkin. (*Stal'*, 1955, (12), 1063–1073). [In Russian]. High top-pressure blast-furnace operation was first introduced at the Kuznets combine in 1950 on a furnace which had worked for over six years without relining. The operation of this and of newly-lined furnaces is described in this article, operating data and constructional details being given. The following were found to be the main features of high top-pressure operation: (*a*) tendency to increased peripheral working, enabling more ore to be charged to the walls; (*b*) greater frequency of incomplete casting, requiring periodic pressure decreases during casting; (*c*) tendency to hanging when top pressure is lowered; (*d*) greater stability of hanging portions of the charge, requiring decreased pressure to restore even working; (*e*) hardly appreciable change in the gas pressure drop through the furnace; (*f*) greater lining destruction through increased gas penetration; (*g*) decreased life of hearth-pad because of increased pressure. In spite of these mainly disadvantageous features high top-pressure operation is still worth while because of the greater uniformity of furnace operation, greatly decreased flue dust loss and increased productivity. For the two furnaces considered, operating mainly at top pressures of 1·3–1·7 atm. (absolute), productivity increased by 6·3–9·4% and for one the coke rate decreased by 2·1%: blower capacity limited further utilization of the advantages of the technique. It is recommended that for the wider use of high top-pressure operation, the production of more powerful blowers should be undertaken, the quality of refractories improved and that the design of individual parts of the furnace be critically examined with a view to improvements.—S. K.

Temperatures and Heat Flow in the Hearths of Blast Furnaces with and without Underhearth Cooling. V. Paschkis and T. Mirsepassi. (*Iron Steel Eng.*, 1956, **33,** June, 116–132). Temperature distribution in blast-furnace bottoms has been investigated using carbon and refractory combinations, and underhearth cooling has also been considered. Heat flow is considered and treated mathematically, erosion and corrosion being disregarded. Depths of penetration and hearth sections with isotherms are shown and salamander size discussed. Special and radial underhearth air and water cooling systems are described and frozen thickness tabulated. The figures apply to 28-ft furnaces.

A Century of Cowper Stoves. D. Petit. (*J. Iron Steel Inst.*, 1957, **185,** April, 501–509). [This issue].

Rate of Reaction of the Solid Components of Blast-Furnace Slags. B. A. Shil't, A. P. Lyuban and V. G. Manchinskiĭ. (*Stal'*, 1956, (4), 303–307). [In Russian]. The following conclusions are drawn from the results of a laboratory investigation of solid phase reactions between components of blast-furnace slags: (1) Appreciable quantities of solid silicates and aluminosilicates of calcium, manganese etc. can be found in the blast furnace before the melting zone is reached; (2) the formation of the aluminosilicates of calcium at 1200–1300° C is much more rapid than those of its silicates and aluminates; (3) manganese silicate is formed in the solid state considerably more rapidly than calcium silicate; (4) the rates of formation are diffusion and contact surface controlled, and increase sharply as the melting temperature is approached.

Moving-Bed Processes—Present and Potential Applications. R. E. Vener. (*Eng. Min. J.*, 1956, **157,** Oct., 89–99). Application to the blast-furnace and to other metallurgical processes are mentioned.

Work at the Low Shaft Furnace at Ougrée. F. Paschal. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, No. 9, 1771–1775). A progress report on recent work at Ougrée in Belgium on the International low shaft furnace is presented. The particle size of the burden has been found of considerable importance and it is necessary to limit the charging of fines. The optimum size is between 5 and 25 mm. The types of solid fuel which can be used in the low shaft furnace are considered.—B. G. B.

Study of the Turbulent Zone at the Tuyere Nose of the Low Shaft Furnace at Ougrée. F. Paschal and R. Biver. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, No. 9, 1777–1791). The great importance of the behaviour of material in front of the tuyers in a low shaft furnace is explained. The results of tests carried out on a model of a low shaft furnace using wooden shapes and semi coke and tuyere sizes of 60, 80, and 140 mm diameter are described. The results of a large number of experiments are examined statistically and compared with those of Wagstaff in America.—B. G. B.

Desulphurization of Basic Iron with Calcium Carbide. E. J. Wittenberger. A. J. Deacon, and L. C. Hymes. (*Blast Furn. Steel Plant*, 1956, **44,** June, 644–647, 689; July, 747–754). The efficiency of the desulphurization of basic pig-iron by the injection of finely divided calcium carbide entrained in a stream of nitrogen has been studied. Tests have been carried out in ladles containing up to 78 tons of iron using a graphite lance dipping into the metal. The desulphurization treatment was found to be reproducible under practical operating conditions. Full details of the experimental techniques used and of the results obtained are given.

The Oxygen Content of Wüstite in Equilibrium with Various Gases. N. A. Hogard and P. N. Jensfelt. (*Jernkontorets Ann.*, 1956, **140,** (7), 467–493). [In Swedish]. The oxygen content of wüstite was studied by reducing pure Fe_2O_3 with mixtures of CO and CO_2 at 810, 980, and 1150° C. From curves showing the percentage oxygen in the wüstite as a function of CO in the gas further curves were plotted for constant oxygen content in the wüstite phase in the Fe–C–O equilibrium diagram. These were extrapolated to higher and lower temperatures and the data in the Fe–C–O system were converted to the Fe–H–O system. The wüstite field in the Fe–O system was plotted and the activities of O and Fe calculated for various oxygen contents.—G. G. K.

DIRECT PROCESSES

Direct Iron in Canada. H. Freeman. (*Trans. Canad. Inst. Min. Met.*, 1956, **59,** 326–329; *Canad. Min. Met. Bull.*, 1956, **49,** Aug., 566–569). A process is described in which iron powder is produced on a commercial scale by direct reduction of iron oxide. A review of the factors which led to the development of the process in Canada are given with a diagram of the furnace and a flowsheet.—R. F. P.

PRODUCTION OF STEEL

Steelmaking Developments During the Past Decade. K. L. Fetters. (*Indust. Heating*, 1956, **23,** July, 1429–1438). A statistical analysis of American steel production figures is presented from which it is concluded that 80% of the increase in production has been due to larger furnaces and the remainder to better practice such as desiliconizing, slag control, and improved refractories, which are briefly considered.

Russian Steelmaking. (*Mét. Constr. Mécan.* 1956, **88,** June, 547–556). A general review is presented of the Russian steel industry.—B. G. B.

Basic Principles Applicable to Steelmaking in Founding Practice. T. A. Cosh and R. J. Sarjant. (*Found. Trade J.*, 1956, **101,** Sept. 6, 251–264). The physical chemistry of steelmaking is discussed with particular reference to the electric-arc melting process as used in steel foundries. The reactions taking place in the metal and in the slag during the melting, refining and deoxidation of the steel are considered in detail. The basic thermodynamic principles involved are explained in an appendix.—B. C. W.

Magnitogorsk Inventors and Rationalizers in the Struggle for Technical Progress. I. M. Krasinskiĭ. (*Stal'*, 1956, (4), 293–294). [In Russian]. Some new devices and improved methods invented by personnel at the Magnitogorsk metallurgical combine are described, with estimates of the economies obtained by their introduction into practice.—S. K.

General Maintenance Operations and Control at Fairless Works. R. L. Leventry. (*Iron Steel Eng.*, 1956, **33,** Sept., 110–118). Plans, photographs, and charts are shown with a description of layout and services. Details are also given in discussion.

Oxygen Steel in the United States. C. R. Austin. (*Iron Steel Eng.*, 1956, **33,** May, 64–68). This article describes the oxygen converter steel plant at McLouth Steel. Production operations with the top-blown oxygen converter show that this is a practical and economical method for making steel.

A Review of Oxygen Applications in Iron and Steel Making. A. N. Whiting. (*Engineer Foundryman*, 1956, **20,** Feb., 50–55). Experience of European and American operators of the use of oxygen in Bessemer, electric arc and open hearth steelmaking, the cupola and Tropenas converter, and to the blast furnace is reviewed. The Linz–Donawitz process is also described.—A. D. H.

Radiation Injury to Eyes No Danger During Pouring. W. Schweisheimer. (*Foundry*, 1956, **84,** Sept., 272, 274, 275). The effects of infra-red and ultra-violet radiation on the eyes are discussed in relation to the possible damage caused by the radiation from hot metal and electric arcs.—B. C. W.

Maintenance and Development of the Small Tonnage Steel Plant. R. D. Bradley and D. W. Petty jun. (*Iron Steel Eng.*, 1956, **33,** Sept., 190–195). An integrated programme is outlined and various specific improvements are described and illustrated.

The Blast Furnaces. (*Handel en Industrie*, 1956, **11,** July 31, 315–317). [In Dutch]. This instalment of the serial article under the above title covers a brief general description of the smelting shop, steel ingot and block rolling mills, also the hot and cold strip rolling mills of the Royal Dutch Steel Works at Ijmuiden (Holland).—F. R. H.

New Convertor Lines. P. Leroy. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, **13,** No. 7, 1405–1413). Changes in the lines of Bessemer convertors are proposed as a result of studies published elsewhere on models and on the full scale.—B. G. B.

Increase in Productivity at a Thomas Steelworks by the Use of Convertors with Large Hearths. L. Septier, J. de Hedouville, P. Leroy, and L. de Saint-Martin. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, **13,** No. 7, 1415–1444). A description is given of the enlargement of the convertors at the Hagondange works of U.C.P.M.I., France, which enabled an increase in production from the five existing convertors to be obtained without necessitating the construction of a sixth.—B. G. B.

Future Trends of the Pneumatic Process.—J. E. Stukel. (*J. Met.*, 1956, **8** June, 763). The author briefly compares the L–D and OV (oxygen-steam) converter processes and discusses the factors influencing the choice of process in a given location.—G. F.

Converter Bottoms with Jets in Hayingen Steelworks. R. Remy. (*Stahl u. Eisen*, 1956, **76,** July 12, 879–881). Apart from the quality of the heat-resisting materials used, the life of converter bottoms with magnesite jets depends mostly on the quality of the magnesite jets themselves. Working conditions are also important, e.g. cell height (which should be as low as possible) and the number of jets (or their cross-sectional area). Some compromise between the various requirements must be found to satisfy the needs for as short a blowing time as possible and as high a flow velocity as the given conditions permit.

Construction of, and Works Experience with, Converter Bottoms, having Magnesite Jets. A. Latour. (*Stahl u. Eisen*, 1956, **76,** July 12, 882–886). Increase in output at the Völklingen works was made possible by partial substitution of magnesite for tar-dolomite bottoms. Further increase is expected on completing the conversion to magnesite.

Second and Third Oxygen Converter Plants in U.S. Under Construction. (*J. Met.*, 1956, **8,** June, 762). Oxygen converter plants using the "L–D" process are now under construction at Jones & Laughlin's Aliquippa plant and at Kaiser Steel Corporation's Fontana plant. The process is outlined diagrammatically.—G. F.

A Comparison of the Oxygen Converter Process with the Classical Steelmaking Methods. A. Legat. (*Schweiz. Arch. Wiss. Techn.*, 1956, **22,** June, 200–203). The top-blown oxygen converter process has more in common with the O.H. than with the basic Bessemer process. In the symmetrical converters used at Donawitz, the oxygen blown on to the surface of the melt produces a liquid reactive slag which takes

part in the physico-chemical processes of steelmaking as in an O.H. furnace. Dephosphorization can be completed before decarbonization and the converter handles pig with phosphorus contents too high for normal O.H. practice. The converter steel is low in nitrogen and trace elements with a consequently lower tensile strength than similar O.H. products. This softness is advantageous for wire manufacture and cold rolling. Improved welding properties and freedom from brittle fracture are also shown by the products of the oxygen converter compared with O.H. steels of the same quality.—J. R. P.

Oxygen in Steelmaking. (*Metallurgia*, 1956, **54**, Sept., 133–137). A description is given of a new tonnage oxygen plant at Margam for the Steel Company of Wales. It has a capacity of 100 tons per day.—B. G. B.

Tonnage Oxygen. (*Coke Gas*, 1956, **18**, Oct., 395–401). An account of the developments in manufacturing large quantities of oxygen for the steel industry is given. The process is described and the approximate cost per ton is shown.—R. F. P.

Three Years of LD-Steel, Vöest 1953–1956. (1956, pp. 70). An account of the Linzer Düsenverfahren Process. **Preface.** W. Hutzinger. (5–9). An outline of the installation of the plant, with statistics. **Metallurgical Principles and Economy of Steel Refining with Pure Oxygen by Top Blowing.** H. A. Trenkler. (10–16). A general account is given of the process, a comparison with O.H. and Bessemer processes, and an outline of operating methods and steel composition. Yields and economic factors are mentioned. **Three Years of LD-Operations.** R. Rinesch. (17–22). More details of vessel construction, charging conditions, working procedure and production programme are given. **Operation Experiences in Steelmaking.** F. Klepp. (23–28). Development is outlined and further details of operation and product given. **Properties of Rimming and Killed LD-Steels.** H. F. Hauttmann (29–51). The refining process is described in detail and the products examined with sulphur prints and the rolled material by impact and other tests, with comparison with other steels after cold reduction. Welded joints are also examined and the various grades are tested according to appropriate standard specifications. Experience at other works is included. (30 references). **Extension of the LD-Steel Plant.** H. Schaden. (52–63). An account of the plant with photographs and plans and details of buildings and ancillary equipment. **Patent Situation of the LD-Process.** E. Hochegger and K. Kafka. (64–66). A general account of development, titles of Austrian patents, and some licencees is given. **Appendix. Economic Purification of Gases by Heat Recovering from Waste Fumes of LD-Vessels.** R. Kemmetmüller and A. Poppy. (68–70). The brochure is illustrated, partly in colour.

Basic Steel Obtained by Blowing with Oxygen-Carbon Dioxide Mixture. P. Boutonnet, A. Richard, P. Mathieu and R. Maret. (*Rev. Mét.* 1956, **53**, Aug., 575–618; Sept., 665–681). Results obtained during the manufacture and subsequent treatment of ingots produced from 50 casts of steel produced by this technique are given. Details of the operation of the convertors and the gas plant are given. Tensile and resilience tests have been made on slabs and plates together with determination of the transition temperature in the annealed and aged states. The mean nitrogen content was found to be 0·003%. A number of tests has been carried out on an industrial scale to compare the steels with those from other methods of manufacture. Results obtained by two motor car firms show that sheet steel produced by the oxy-carbon dioxide process is perfectly satisfactory for deep drawing operations.—B. G. B.

Comparison of the Energetic and Economic Efficiencies of the Basic Converter and the Linz-Donnawitz Oxygen-Lance Processes. A. Děkanovský. (*Hutnické Listy*, 1956, **11**, (4), 241–248). [In Czech]. The thermal efficiency of the oxygen process was evaluated to be 73%, compared with 55% for the Thomas converter, and 30% for the open-hearth furnace. The oxygen process is found to be economically inferior to the Thomas process if the former works with ore only. The converse is true if half the charge consists of scrap.—P. F.

New Control Instruments for Bessemer Steelmaking. P. Leroy. (*J. Met.*, 1956, **8**, June, 764–768). Descriptions are given of four instruments developed by IRSID to assist in the control of the Bessemer process. They are: (1) the volume-debitgraphe, recording both air flow rate and total air volume blown; (2) the two-colour pyrometer, aimed at the bath through a tuyere; (3) the flame pyrometer, measuring the true temperature of the flame; and (4) the opacimeter, which records the opacity of the flame. The method of interpreting readings obtained is discussed.—G. F.

On the Basic Pneumatic Processes of Steelmaking. P. Coheur and H. Kosmider . (*J. Met.*, 1956, **8**, June, 754–759). The authors discuss the present state of development of the basic Bessemer process. Particular attention is paid to the production of low-phosphorus, low-nitrogen steels by control of the standard process, and to the principles of the top-blowing process. The improvement in steel quality resulting from these latest developments is indicated.—G. F.

One Hundred Years of Bessemer Steelmaking. A. B. Wilder. (*J. Met.*, 1956, **8**, June, 742–753). The author discusses the early history of the Bessemer process and traces the development of pneumatic processes to the present day. He describes the origin of the basic converter and the side-blown converter, and considers the problem of fume. Control of the blow in the production of low-nitrogen steel is described, and finally the development of the top-blown converter is discussed.

Interrelations Between Phosphorus Content of Thomas Melts, Iron Content of Slag, and Oxygen Supply During Last Minutes of Blowing. H. vom Ende and G. Mahn. (*Stahl u. Eisen*, 1956, **76**, Apr. 5, 390–393). The influence of slag iron-content and of temperature on the phosphorus-content of steel is indicated, and the consumption of oxygen discussed in relation to slag formation and the burning away of phosphorus.

Effect of Oxygen Input Rates in the Decarburization of Chromium Steel. G. W. Healey and D. C. Hilty. (*Blast Furn. Steel Plant*, 1956, **44**, Sept., 1048–1051). The rate of rise in temperature, metallic oxidation and oxygen utilization during the decarburization of chromium steel by oxygen lancing is discussed. High oxygen rates result in short oxidation periods, reduced oxidation of chromium and high bath temperatures. For a given set of conditions there is a critical oxygen rate which must be exceeded if effective decarburization is to be attained.—B. G. B.

Oil Burners for Steelmaking Furnaces. M. Hansen. (*BWK*, 1956, **8**, July, 338–339). Recent developments are reviewed, with special reference to the work on burner design and flame-radiation carried out by BISRA.—P. F.

Modern European Methods of Open-Hearth Furnace Construction. F. Bartu and H. Leopold. (*Inst. Hierro Acero*, 1956, **9**, Apr., 386–404. Special Number). [In Spanish]. An illustrated account is given of modern techniques of furnace construction dealing in turn with the framework, brickwork, roof construction, gas and air ports, and ancillary equipment.—P. S.

Organization of Work During Repairs of O.H. Furnaces. I. M. Denisenko, K. E. Kapustin, and P. G. Maksimov. (*Stal'*, 1956, (4), 317–323). [In Russian]. Investigations carried out at the Kuznetsk metallurgical combine on the organization of O.H. repairs are described. Details are given of the improvements obtained by the application of the results of the investigations.—S. K.

Elements of the Hydromechanics of the Bath and the Thermal Working of Open-Hearth Furnaces. S. I. Sapiro. (*Stal'*, 1956, (4), 356–358). [In Russian]. Recently published work, especially that of M. A. Glinkov, on factors influencing the transfer of heat to the O. H. furnace bath is critically discussed, special attention being given to the condition of the slag and metal layers.—S. K.

Stocking and Transport of Refractories under the O.H. Shop Working Stage. N. A. Shmidt. (*Stal'*, 1956, (4), 359). [In Russian]. Measures taken at the Zaporozhstal' works to improve the movement of refractory materials during the repair of O.H. furnaces are outlined.—S. K.

Use of Oxygen in the O.H. Furnace Flame at the Zaporozhstal' Works. B. V. Sevruk, A. V. Leskov, and I. S. Marakhovskii. (*Stal'*, 1955, (12), 1074–1081). [In Russian]. Operating experience with 185-ton O.H. furnaces supplied with oxygen is described. The elevation of the oxygen content of the air to approximately 25% led to the following results: (*a*) the production of basic-roofed furnaces rose by 21%, specific fuel consumption falling by about 15% (with oxygen consumption at 35 m³/ton); (*b*) due to increased wear of the main roof the campaign life decreased by 2·4%; (*c*) oxygenation did not appreciably change the nature of processes in the furnace, accelerating them only; (*d*) oxygena-

tion did not greatly cheapen the steel. Oxygenation resulted in some lack of balance in the auxiliary operations.—S. K.

The Refining of Stahleisen by the Oxy-Steam Process. H. Kasmider and A. Weyel. (*Blast. Furn. Steel Plant*, 1956, **44**, May, 483–492, 502). A description is given of full-scale convertor experiments involving the blowing of stahleisen (hot metal with high carbon, relatively high manganese and silicon and very low phosphorus) with oxygen and steam. The bottom blown and surface blown convertor practices are compared and differences in practical application and economics are discussed. A feature of oxy-steam practice is the absence of fume. A 7% increase in scrap usage can be obtained by after-burning the convertor gas.—B. G. B.

Reactions Between Iron Bath and Phosphate Slag. O. Peter, W. v. d. Esche, and W. Oelsen. (*Arch. Eisenhüttenwesen*, 1956, **27**, Apr., 219–230). The authors describe experiments with tricalcium phosphate, dolomite, and lime crucibles. The composition of the slag and the distribution of phosphorus and sulphur in the experimental melts are indicated. Test results are compared with industrial experience.

Electric Versus Openhearth. J. E. Wilbanks. (*Metal Progress*, 1956, **70**, Sept., 118–119). A short discussion of the merits of electric over openhearth steelmaking is presented. Electric steelmaking is considered to have considerable advantages both economical and practical.—B. G. B.

Development of American Arc Furnace Practice for Steel Making. (*J. Four. Elect.*, 1956, **65**, May–June, 94–99). An illustrated review of the development of American electric steelmaking practice is presented.—B. G. B.

Hydrogen and Nitrogen in the Working of Steel in the Basic Electric Arc Furnace. G. Triginer Boixeda. (*Inst. Hierro Acero*, 1956, **9**, Apl.-June, 650–655). [In Spanish]. The principles involved in the elimination of hydrogen and nitrogen from liquid steel are discussed. Nitrogen can be removed by fixation into the slag as a stable nitride, using titanium or zirconium, or by flushing. Hydrogen can be removed by oxidation. The sources of these gases e.g. the charge, melting down, deoxidation, desulphurization, alloy additions and casting pit practice are considered and the beneficial effect of the refining period is described. The hydrogen and nitrogen contents are minimized by using a vigorous refining period—preferably with oxygen—and taking precautions subsequently. When this proves insufficient, argon flushing is the only resort.—P. S.

The Utilization of Renn-Krupp Nodules for Steel Making in the Electric Arc Furnace. J. A. Riviere. (*Inst. Hierro Acero*, 1956, **9**, July, 739–747. Special Number). [In Spanish]. Two nodule sizes were available (*a*) 5 to 10 mm dia. containing 1·0% C, 0·8% P, and 0·7% S, and (*b*) 20 to 60 mm dia. containing 0·9% C, 0·5% P, and 0·5% S and their use as part of the charge was considered. The problem of phosphorus and sulphur removal is discussed and basic requirements for nodule treatment were established as a result of trials using 10 and 20% additions to the charge. Other trials were made using 60 and 100% nodules and these are used to illustrate the need for an intense oxidation period which is helped by recarburizing, and by ore and lime additions. (11 references).

Progress with Special Steels. G. Grenier. (*Echo Mines*, 1956, July, 397–399). A review giving compositions and uses.

Metallurgical Problems of the Steels for Superstructures. Development Work in Austria. A. Legat. (*Inst. Hierro Acero*, 1956, **9**, Apr.-June, 638–644). [In Spanish]. In a review of the development of constructional steels, the balance between alloying, heat-treatment, and cost is discussed. Welding requirements demanded low carbon and alloy contents so that development work was necessary in order to obtain better properties. The progress of such work with particular reference to the author's own laboratories (Osterreichisch-Alpine Montangesellschaft) are described, and particular reference is made to the manganese-silicon types of steel as well as to pure-oxygen-blown convertor steel.—P. S.

Some Effects of Silicon on the Mechanical Properties of High Strength Steels. C. H. Shih, B. L. Averbach and M. Cohen. (*Trans. Amer. Soc. Metals*, 1956, **48**, 86–118). An improvement in the high strength mechanical properties in 4340 and 4325 steels has been obtained by increasing the silicon content to 1·5%. The results of tests on these steels at the same tempering temperatures and after treatment at the same strength level are given in tabular form. Tests indicate that the endurance limits and the elastic limits may be related.—E. E. W.

Oxidation Resistant Silicon Aluminium Steels. E. A. Brandes. (*Fulmer Research Institute Special Rept. No. 2*, 1956, pp. 40). Steels with 2–3% Si and 0·5–1% Al are as resistant to high-temperature oxidation as 18–18 steel and have ductility at room temperature sufficient for forming operations. Mn minimizes the effect of segregated sulphur. Scaling resistance in flue gas and steam is high and is improved by coating with Al. At ordinary temperatures resistance to corrosion is not better than that of mild steel, and strength at 600° C is low.

Nuclear Industry Wants Better Steels. R. C. Dalzell. (*Iron Age*, 1956, **177**, June 21, 112–114). The roles of specific alloys and the importance of properties of individual elements, in plants connected with atomic energy are considered. It is concluded that there will be a gradually growing moderate demand for stainless and other steels for the outer structures of reactors and for associated chemical plants, but there is scope for new and better grades.—D. L. C. P.

Making 200-Type Stainless. G. W. Hinkle. (*Steel*, 1956, **139**, July 9, 94–96). Types 201 and 202 stainless steel have compositions in the ranges: C, 0·15% max; Mn, 5·5–10·0%; Ni, 3·5–6·0%; N, 0·25% max. Production, processing and properties are considered.—D. L. C. P.

Pouring Small Moulds with Large Ladles. J. L. Jennings and J. R. Patton. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 202–206). At General Steel Castings Corporation, it is often necessary for castings ranging from 10 tons to 100 lb to be poured from the same ladle. Details are given of the practice of using a nozzle reducer, by means of which the effective nozzle size can quickly be reduced from 4–5 in. for the large castings to 1½ in. for the small castings.

The Autopour at Republic Steel Company. K. F. Waggener. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 54–55). The electrically-valved hydraulic stopper control gear (the "Autopour") installed at Republic Steel Corporation is briefly described, and the advantages gained from its use are discussed.—G. F.

Influence of Hot-top Coverings on Steel Quality of Plain Carbon and Low-alloy Grades of Steel. P. H. Smith and J. F. Elliott. (*Amer. Inst. Min. Met. Eng. Proc. Nat. O.H. Comm.*, 1955, **38**, 22–44). The authors have studied the effects of different hot-top additions on feeding efficiency, segregation, and quality of prime product as indicated by cleanliness and performance in blanking tests. It is concluded that an inert covering applied immediately after teeming is superior to an exothermic covering from the standpoint of quality, and double-burnt dolomite is considered the most suitable material. A stripping time which allows the formation of a round top crust is recommended.—G. F.

Benefits Derived from the Use of the Bath Thermocouple. W. R. Huber and L. G. Ekholm. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 57–61). The use of the bath immersion thermocouple at works of the United States Steel Corporation has resulted in better teeming performance, lower mould consumption, decreased bottom and bank delays, and better quality. Data illustrating the improvements are given.—G. F.

Rimming Steel Action as Observed in Motion Pictures. W. H. Mayo. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1955, **38**, 139–140). The author has taken cine-films at 24 and 64 frames/s of rimming steel rising in the mould. The main features observed are outlined.—G. F.

Conditions for the Separation of Oxide Impurities from Steel in the Pouring Ladle. E. Plöckinger. (*Stahl u. Eisen*, 1956, **76**, June 14, 739–748). The author reviews current knowledge of the conditions for the formation and separation of non-metallic impurities. The significance of the individual stages in the production of steel with respect to the purity of the latter, the state of affairs in the pouring ladle, conditions for separation of the reaction products of furnace and ladle, de-oxidation in the manufacture of Siemens-Martin and electric steels, and the indications from the appearance and composition of observed inclusions are among the matters treated.

The Use of Lunkerite for Reducing Ingot Head Losses. K. Hýbek. (*Hutnik*, 1955, **5**, (10), 291–293). [In Czech]. A special mould capable of holding a constant volume of lunkerite or other exothermic insulant was used in time/temperature experiments on ingot heads. Eighteen varieties of insulants were tested; these are tabulated in the order of their respective efficiencies. Recent Soviet work on this subject is briefly mentioned.—P. F.

Continuous Casting of Unkilled Thomas Steel. H. Kosmider, H. Neuhaus and A. Weyel. (*Stahl u. Eisen*, 1956, **76,** May 31, 668–678). The authors describe experimental apparatus for the determination of temperature losses between the converter and the continuous casting plant. The freezing process, segregation, rolling, and the operational advantages and disadvantages are discussed.

Continuous Casting of Steel in France. A. Michel. (*Inst. Hierro Acero*, 1956, **9,** July, 831–840. Special Number). [In Spanish]. An illustrated account of the continuous casting plant at the Holtzer factory in France is given. A variety of special steels are made and these have properties comparable with similar steels made in the ordinary way.—P. S.

The Continuous Casting of Steel at the Établissements Cail at Denain. R. Fievet. (*Mém. Soc. Ing. Civils France*, 1956, May-June, 174–189). A review of continuous casting techniques is first given. The decision which led the Établissements Cail to adopt this casting method are discussed. The machine used is constructed according to the Junghans patents. An hourly production of 60 tons of ingots is achieved and 25,000 tons of metal were cast to the end of 1955. A wide range of steels have been used including mild and alloy varieties. 25 photomicrographs of ingot sections are reproduced.—B. G. B.

Use of Sponge and Ball Iron in the Production of Quality Steel and Special Alloys. I. L. Lur'e and N. N. Timoshenko. (*Stal'*, 1955, (12), 1135–1140). [In Russian]. Large scale tests on the use of sponge iron made from 68% Fe Krivoi Rog ore are described, which showed the suitability of this material for producing special alloys, quality steels, irons for the electrical industry and alloys with precise specifications.

Some Aspects of Hardenable Alloy Steels. H. J. French. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8,** June, 770–782). The development of alloy steels in the past 50 years is traced, and it is shown how improvements in knowledge have led to lower and lower contents of the two main alloying elements, nickel and chromium. Chemical composition is shown to affect the ductility and notch toughness of tempered martensite significantly, particularly after slack quenching, and the effect of retained austenite on mechanical properties and service life is discussed. It is concluded that the mechanical properties of triple-alloy Ni–Cr–Mo steels are superior to those of double or single alloy steels.—G. F.

The Use of Molybdenum in Quality Steelmaking. R. E. Warriner. (*J. Four Elect.* 1956, **65,** July-Aug., 125–127). A short survey of the uses of molybdenum in steels and also as a lubricant is presented.—B. G. B.

Development of Weldable General Structural Steels. C. Schaub. (*Tek. Tidskr.*, 1956, **86,** June 19, 585–589). [In Swedish]. After defining the qualities required to ensure weldability the author discusses the influence of the yield-point u.t.s. ratio on steel properties. Steels described having high ratios include Colduct, Aldur and HSB. Tables show their characteristics and compositions.—G. G. K.

German Alloy Steels. Some Notes on Present Practice to Conserve Scarce Materials. H. L. Walth. (*Automobile Eng.* 1956, **46.** Feb., 55–58). Analyses and properties are tabulated, and discussed and compared with British steels in the text.

High Nitrogen Austenitic Cr–Mn Steels. V. F. Zackay, J. F. Carlson, and P. L. Jackson. (*Trans. Amer. Soc. Metals*, 1956, **48,** 509–525). Cr–Mn austenitic steels containing 0·5% and higher of nitrogen were prepared by a pressure-melting and -casting technique. The creep-rupture properties were equivalent to a commercial heat resistant alloy (16/25/6). Good combinations of strength and ductility in both the annealed and cold worked state resulted from the unusually high interstitial nitrogen content.—E. E. W.

Amount and Character of Oxide Inclusions in Chrome-Manganese Case-Hardening Steels between Melting in Basic Siemens-Martin Furnace and Solidification. E. Plöckinger. (*Stahl u. Eisen*, 1956, **76,** June 28, 810–824). The author describes tests on works melts of chrome-manganese case-hardening steels from the basic 60 metric ton Siemens-Martin furnace. These were conducted to investigate the quantities, chemical composition, and structure of oxide inclusions, and the variation in quantities, chemical composition, and particle formation of these inclusions from the time at which the steel was in the furnace to the time of solidification into ingots. The results are compared with the variation in quantities of inclusions in various constructional and tool steels from the basic Siemens-Martin furnace or the basic arc furnace. The reactions during deoxidation and pouring are discussed. Conclusions relating to the production of steels containing small quantities of oxide inclusions are drawn.

Killing of Deep Drawing Steels in the Mould. W. Gerling and K.-O. Zimmer. (*Stahl u. Eisen*, 1956, **76,** June 28, 799–805). Faults in killed, semi-killed, and unkilled cast soft steels are reviewed. "Chemically capped steel" is defined. Conditions for the attainment of acceptable quality, the mechanical properties of the steel, economic considerations, and the possibility of producing a deep-drawing boiler plate with stable ageing characteristics are discussed.

Surface Conditioning of Steel Ingots and Billets. G. K. Ihlgren. (*Jernkontorets Ann.*, 1956, **140,** (4), 314–344). [In Swedish]. After deriving a mathematical relationship between output and factors such as the number of flaws to be removed, chip removal capacity of machines and handling time, the author examines their influences individually and draws conclusions regarding the best conditioning method. An analysis is made of machining costs, followed by a detailed comparison between the economics, operating times and capacities of Waldrich planers, billet grinders, turning and milling methods. Cost increases due to material losses are touched upon.—G. G. K.

Hot Tops Increase Ingot Yield. (*Steel*, 1956, **139,** July 30, 100). An application of "Foseco Feedex" hot top compositions (aluminium base) is described. The use of clay hot tops lined with the composition has led to savings on high speed and alloy steel ingots.—D. L. C. P.

Recent Developments in the Continuous Casting of Steel. (*Mét. Constr. Mécan.* 1956, **88,** May, 459–467). A short review of the principal types of continuous casting technique is made and short descriptions of existing machines are given.

Investigation of the Properties of the Metal of a Continuously Cast Ingot. N. L. Komandin. (*Stal'*, 1956, (4), 307–316). [In Russian]. Investigation has shown the superiority of the mechanical and technological properties of continuously cast ingots both in the cast and worked states. Internal cracks are liable to occur, however, with very intense jet cooling, but these can be removed by selecting optimal secondary-cooling conditions. The internal cracks close completely during working, giving products of super-standard qualities. The ingot and the sheets and forgings obtained from it are isotropic in mechanical properties, which are superior to those normally obtained. Mechanical working has little effect on the mechanical properties and is only necessary for welding internal cracks and getting the required shape.—S. K.

Hot-Tears in Cast Steels. R. Garlatti Colussi and J. Villagarcia Gonzalez. (*Inst. Hiero Acero*, 1956, **9,** July, 748–762. Special Number). [In Spanish]. In a review of the problem of hot-tearing, the causes, the factors which influence the phenomenon, and the present day theories are discussed. It is pointed out that moulding technique should be such that hot-spots and stress concentrations are avoided.

PRODUCTION OF FERRO-ALLOYS

Production and Use of Ferro-alloys. H. Cartoux. (*Chim. et Ind.*, 1956, **76,** Sept., 453–470). After a brief historical introduction methods of production are reviewed with special reference to electric furnace methods and to the use of aluminium and silicon. In the section on uses, deoxidation and alloy formation in the steel industry are discussed and the individual alloys, Fe–Mn, Fe–Cr, Fe–V, Fe–Mo, Fe–W, Fe–Ti and Fe–B and some silicides have each a section.

Investigation of the Production of Ferroboron and Nickel-boron from Borate Ores. B. P. Lyakhin. (*Stal'*, 1955, (12), 1104–1112). [In Russian]. It has been shown by small and large scale tests that rich ferroboron or nickel-boron can be produced from borate ores (about 27% B_2O_3) either by aluminothermic or arc furnace methods, the latter being the more advantageous. The aluminothermic method with potassium chlorate gave ferroboron containing 13–14% B and 5–6% Al, the boron recovery being 58–65%. The corresponding figures for the arc furnace alloy which also contains 3–4% Si are 12–13%, 3–4% and 50%, a 36–40% saving of aluminium being achieved. Satisfactory nickel-boron (9–14% B, 3–8% Al) was obtained in a small arc furnace with boron recovery of 30–50%. Beneficiation of the borate ores is essential for high-quality ferro-alloys.—S. K.

FOUNDRY PRACTICE

Report of the 23rd International Foundry Congress, Düsseldorf, Sept. 1956. [In German; Summaries in English and French]. **The Continuous Casting of Iron.** A. Wittmoser. (Paper 101, pp. 12). Research at Gelsenkirchen is described on the production of pressure pipes and on the manufacture of cast-iron parts by a continuous process. **Practice in the Construction and Working of the Basic Cupola in Italy.** D. Masperi. (Paper 102, pp. 12). Cast iron melting is considered and such problems as the use of mixed iron and steel charges, low grade charges, spheroidal graphite iron and high-carbon iron for steel making. The basic and acid processes are compared, and lining materials considered. Analyses and test results on machine castings production over a two-year period are given, and costs compared. **Influence of Gas Scavenging on the Graphitization of Cast Iron.** G. Blanc and N. Volianik. (Paper 103, pp. 13). Passage of gas through the bath is studied with regard to production of the grey form of cast iron. Plain and alloyed irons were used and the gas introduced to the bottom of the melt through graphite tubes. Chill samples showed diminution in the white marginal zone at the contact face. The nature of the gas is unimportant, though air or oxygen cannot be used for long periods or at high temperature without removal of silicon, but inert gases produce no change in composition. The process has been carried out industrially in ladles and inclusions were diminished and castability and machining properties improved. Holding time could be greatly increased. **The Effect of Gas Scavenging on the Magnesium Consumption in Production of Spheroidal Graphite Cast Iron.** W. Patterson. (Paper 104, pp. 11). Gases passed through the melt remove dissolved gases and facilitate the rising of suspended particles and droplets. Nitrogen eliminates oxygen and sulphides and economizes magnesium in production of s.g. iron. Work at Aachen is described and crab graphite formation is interpreted and effects of Ti, V and carbides discussed. **Oxide Patterns Appearing on the Surface of Molten Cast Iron.** O. Madono. (Paper 105, pp. 4). Four patterns are distinguished, due to silicates, which can be correlated with chemical composition and gases present. **The Development of Internal Stresses Leading to the Cracking of Grey Iron Castings.** H. G. Angus and W. G. Tonks. (Paper 106, pp. 6). A review showing that cracking stresses are mainly due to temperature differences which develop where the highest temperature is about 700–750°. Above this the stresses are opposite in direction. Plastic deformation occurs above 700° and ensures that a stress-free system, though with temperature variations, is produced, and subsequent cooling develops strains from this state. The influence of a number of factors on the process, and its effects, are discussed. **Temperature Resistance of Moulding Sands and its Correlation with Casting Defects.** H. W. Dietert, V. M. Rowell, and A. L. Graham. (Paper 107, pp. 11). A dilatometer for sand testing is described in which hot compressive strength can be measured. Failure of the mould surface can be predicted from these measurements and increase of strength or deformation eliminates them. Various types of defects are distinguished and the factors suggesting their appearance are given. Various other tests are given correlating with other types of failure. **Studies on the Evaluation of Moulding Sands.** H. Jungbluth. (Paper 108, pp. 11). The work of Reitmeister in 1927 and after is discussed and the importance of his curves of properties against moisture content confirmed in a general way, though exceptions occur, and also the triangular plot of Götz is shown to be more useful in many cases. It is shown that compressibility can be included in the triangle. **Calculation of the Riser Neck on Sand-Castings.** R. Namur. (Paper 109, pp. 6). The method of calculating the riser has been given previously. A formula for the connecting channel is now advanced. **Behaviour of Green Moulding Sands during Shock Heating in Connection with the Occurrence of Surface Defects.** H. G. Levelink. (Paper 110, pp. 8). Force of expansion is measured and correlated with the formation of scabs, buckles and rat tails. The behaviour of surface layers and their adhesion to underlying material was investigated. **Aspects of Shell Moulding Theory.** B. H. C. Waters and A. Braybrook. (Paper 111, pp. 15). Cold and hot strengths of the mould are considered and the effects of sand and resin type discussed. Effects of segregation and the clay properties are studied and then gas defects and their relationship to gas content and shell permeability. Surface finish, shell closing, running and feeding techniques are described, and casting structure and its modification. Pattern design and costs are briefly mentioned, and comparison with the CO_2 process is made. **Theoretical and Practical Problems of Bentonite Research.** H.-E. Schwiete. (Paper 112, pp. 9). X-ray and thermal analyses are discussed, and the behaviour of montmorillonite on heating to 1200° C is described. Ceramic methods are reviewed and the differences between natural and activated bentonites are shown. **Green Sand Moulding of Large Steel Castings.** C. W. Briggs. (Paper 113, pp. 7). A review of U.S. foundry practice. **Investigations on Sand Mixers and Sand Slingers.** W. Gesell. (Paper 114, pp. 8). A comprehensive review of mixing and mixers and their relation to laboratory tests is given. **Investigation of Isothermal Changes on Cu–Cr– and Ni–Cr–alloyed Cast Iron Containing 0·5% Mo.** A. De Sy and J. van Eeghem. (Paper 115, pp. 10). Seven irons were studied and their microstructures and TTT-diagrams compared and the effects of heating at 250–700° noted. Cast iron with Mo and Cu is suitable for obtaining a bainite–martensite structure and it is confirmed that it favours acicular structure on slow cooling. **The Influence of Silicon and Phosphorus on the Annealing Brittleness of Malleable Cast Iron.** P. Bastien, P. Azou, and Mlle. Winter. (Paper 116, pp. 8). A theoretical explanation is proposed to explain the effects of Si and P. Mechanical tests at room and elevated temperatures, dilatometric tests and X-ray studies were made. **The Automatic Buehrer Moulding and Pouring Plant in the Malleable Iron Foundry of Goerge Fischer Ltd., Schaffhausen.** W. Götz. (Paper 117, pp. 16). **Creep Resisting Steel Castings for Medium and High Temperatures.** H. Zeuner. (Paper 118, pp. 6). Materials are reviewed. **Hydrodynamic Investigations of Mould Filling Capacity.** E. Scheil and D. Pohl. (Paper 120, pp. 6). Flow through sand tubes is studied. Analogies with water flow are discussed. **New Methods in Thermodynamics and in the Calorimetry of Alloys: Their Application to Iron and Steel.** W. Oelsen and E. Schürmann. (Paper 121, pp. 8). Heat contents are calculated and the method of determination by "Quantitative thermal analysis" is described. Curves so obtained are interpreted giving "state patterns" of the alloys. Partial heat contents for iron and alloys are given up to m.p. and solidification and subsequent processes are discussed. **Measurement of Surface Tension of Cast Iron.** D. Pohl and E. Scheil. (Paper 122, pp. 6). Cast iron is studied by the oscillating jet method and the effects of Si, P and S determined. A relation with mould filling capacity is established. **The Physical Strain of Work on Man in the Foundry.** G. Lehmann. (Paper 124, pp. 7). Various operations are considered and improvements suggested. Fumes, dust and noise are also considered. **The Application of the MTM System in the Planning of Foundrywork.** J. Edman. (Paper 125, pp. 11). MTM or Methods–Time Measurement gives a direct index of productivity. Its use at the AB Volvo Pentaverken foundry is described. **Future Problems of Research in Foundry Techniques.** O. Hoff. (Paper 126, pp. 2). [No Summary]. Future aims are given under seven headings after a brief discussion.

New Horizons in Foundry Progress. H. J. Heine. (*Bull. School Mines Met. Univ. Missouri*, 1956, No. 91, 1–14). A review of vacuum melting, pressure moulding, shell moulding, CO_2 process, core shooting and gating and risering, with discussion.

Development Foundry Explores and Improves Techniques. (*Foundry*, 1956, **84,** Sept., 190–191, 193). The equipment installed in the Process Development Section foundry at the General Motors Technical Centre, Warren, Mich., is briefly described.—B. C. W.

Casting Design for Machine Shop Efficiency. E. R. Tichauer. (*Australasian Eng.* 1956, **48,** Mar., 58–63). A lecture. General principles are outlined for the production of round castings, with considerations of grain size effects, internal stresses and porosity. Chills, gates and risers and machining are also discussed.

Layout and Design of Ingot Mold Foundries. G. W. Merrefield. (*Iron Steel Eng.*, 1956, **33,** July, 91–104). Unloading and storage, melting and metal delivery, sand handling, preparation, delivery and storage, moulding, mould and core baking, mould closing, pouring and cooling, shakeout, ventilation, smoke and dust elimination, cleaning, machining and other topics are all briefly discussed.

Big Castings Build a Business. (*Steel*, 1956, **139,** July 30, 104–106). A foundry producing large mould-iron castings is described. Hot metal is obtained from a continuous tapping cupola. Moulds are made from cement-bonded sand, and castings weigh up to 150,000 lbs.—D. L. C. P.

Dimensionally-accurate Castings. J. Hill. (*Found. Trade J.*, 1956, **100,** May 10, 293–300; May 17, 331–336). The various sources of error in the dimensions of castings are discussed in detail. Among the variables considered are inherent metal contraction characteristics, mould and core uniformity, ramming methods, moulding sands, grain size and distribution, mould pressures, gating and feeding practice, mould and pattern equipment, and casting design.—B. C. W.

Australia's Largest Mechanized Foundry. (*Castings*, 1956, **2,** July, 22, 23, 25, 29, 31–33, 35). A description is given of the lay-out, equipment, and operating procedure at the General Motors–Holden's Mechanized Foundry at Fishermen's Bend, Melbourne, which produces all the iron castings used in Holden vehicles.—B. C. W.

Modern Practice Typified By New Grey Iron Foundry. W. G. Gude. (*Foundry*, 1956, **84,** Oct., 104–111). The lay-out, equipment, and practice at the new iron foundry of the Bullard Co., Bridgeport, Conn., is illustrated and described. The foundry produces machine tool castings and has a melting capacity of 125 tons/day.—B. C. W.

Establishing a New Foundry. F. Warga. (*Found. Trade J.*, 1956, **101,** Aug. 30, 235–236). The equipment, facilities and foundry practice at the ferrous foundry of the AiResearch Manufacturing Co., Los Angeles, is briefly described.—B. C. W.

Practical Mechanization for Small Foundries. C. V. Nass. (*Bull. School Mines Met. Univ. Missouri*, 1956, No. 91, 34–39). A general account mainly on a cost basis.

Mechanized Productions of Castings for Diesel Generators. (*Mech. Handling*, 1956, **43,** Sept., 545–550). An account of the procedure at Blackstone and Co.'s Stamford plant, with plans and illustrations.

New Furnace and Humidity Control Equipment in Mechanized Foundry Improve Quality of Iron. (*Indust. Heating*, 1956, **23,** July, 1410–1418). Two cupolas fitted with hot blast and humidity control equipment are used with a 15 ton are holding furnace in a Chicago mechanized foundry producing malleable iron.—A. D. H.

Mechanizing Cupola Charging. (*Iron Steel*, 1956, **29,** Apr., 127). Brief details are given of a rail-mounted crane, used in conjunction with a weigh-car to increase efficiency of cupola charging.—G. F.

The Behaviour of Moist Green Sand under the Effect of Sudden Heating and the Occurrence of Surface Peeling. H. G. Levelink. (*Metalen*, 1956, **11,** Sept. 15, 378–381). [In Dutch]. This paper studies the expansion phenomena occurring at the surface of samples of green sand when subjected to sudden heating. The experimental results clearly indicate that peeling is influenced by the cohesion between the dried upper and the moist underlayer of sand and also by the kind of sand involved. There is also the expansion force created by the impeded expansion which is capable of being largely counteracted by the inclusion of ingredients such as wood flour or coal dust in the mix.—F. R. H.

Construction and Working of Welding Sand Separators. E. Knipp. (*Giesserei*, 1956, **43,** June 7, 320–321). The general principles governing the construction and the method of working of sand separators is first discussed. A new design of separator with a tipping head and an alternate mixer for beneficiation of the sand is described in some detail. The advantages are described.—R. J. W.

Silicon-carbide Shapes as Denseners in the Foundry. H. W. Griffiths. (*Found. Trade J.*, 1956, **100,** Jan. 19, 75–77). The advantages of silicon carbide denseners over those made from cast iron are summarized. The method of using them is briefly described and examples of their applications are given.

Heaters for Drying and Pre-Heating Casting Ladles. (*Fonderie*, 1956, Feb., 74–75). The drying and pre-heating of ladles with propane is briefly discussed.—B. C. W.

The Skin Drying of Green Sand Moulds. H. R. Wood. (*Castings*, 1956, **2,** Mar., 15, 17). A gas-fired radiant heating unit for the skin drying of green sand moulds is briefly described.—B. C. W.

The Production of Chemically Hardened Moulds (CO_2-Process). L. Petrzela. (*Giessereitechn.*, 1956, **2,** Aug., 178–179). The 10-year old history of the production of chemically hardened moulds is reviewed. Methods of recovering old sand are discussed. The alkali can be rinsed out with water, or practically all the CO_2 can be expelled by heating to 500° C and conversion of the sodium silicate produced into insoluble form. The hardening reaction is reversible, if water is used under pressure, at temperatures down to 100°.—L. J. L.

Will the CO_2 Process Mark a New Epoch in Foundry Practice? P. Trippe. (*Metalworking Prod.*, 1956, **100,** Jan. 26, 136–144). This article discusses the change over from conventional sand casting at Western Foundries Ltd., to the new CO_2 process. Considerable savings in time, machining and labour are achieved, and accuracy is very high. It is claimed that the financial savings by using this process is at least £1 per ton on finished cores.—M. A. K.

Discussion on the CO_2 Process. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1956, **6,** Aug.). **Introduction.** S. H. Russell. (260–262). A short review of the development of the CO_2 process for hardening of cores and moulds is given. **The CO_2 Process.** A. Tipper. (263–266). The advantages and limitation of this process are described in terms of the physical and chemical changes which occur. **The CO_2 Process.** D. V. Atterton. (267–274). The theory of the hardening reaction, the sand properties and methods of gas application are considered. The results of tests carried out to determine the chemical reactions occurring during gassing are reported. A number of photographs illustrating practical techniques which have been developed are shown and discussed. **Surface Finish of Castings Produced by the CO_2 Process.** K. Steiner. (275–277). The influence of carbonaceous additions made to moulding sands on the surface finish of castings is discussed. A low permeability is the first essential in obtaining a good surface finish. When it is uneconomical to use fine moulding sands, pelleted pitch and plumbago additions are commonly used. **The Origins of the Carbon Dioxide, or Hargreaves-Poulson Process.** J. R. Platt and D. W. F. Hardie. (278–282). An historical account. **Foundry Experiences with the CO_2 Process. Introductory Remarks.** W. B. Parkes. (283–285). An attempt is made to explain the reasons for the wide differences in the practical techniques employed by different foundries using the CO_2 process. The build up of sodium carbonate and silicates in used moulding sand is also considered. **Foundry Experiences with the CO_2 Process.** G. B. Taylor. (286–291). The use of this process at the jobbing foundry of Messrs. Ashmore, Benson and Pease is described. Within 8 months of the introduction 90% of the dry sand work and 95% of the cores were produced by the CO_2 process. 4000 to 4500 tons of castings are made per year. The development of the technique in the foundry is discussed. **Foundry Experiences with the CO_2 Process.** C. R. Porter. (292–293). A short note on the successful use of this process by Messrs. Newman, Hender and Co. Ltd. for dealing with their larger castings which are not made by shell-moulding is given. **Foundry Experiences with the CO_2 Process.** J. E. O. Little. (294–298). The development of this process at Messrs. Glenfield and Kennedy Ltd. is described. 12,000 tons of castings are made per year, the majority being Meehanite castings with a high metal pouring temperature and for the most part cored. The difficulties encountered are reported and the CO_2 process is now considered successful. **Foundry Experiences with the CO_2 Process.** A. Talbot. (299–304). The effect of the introduction of the process at Messrs. Western Foundries is described. The foundry employs less than 50 people and the productivity has increased by 70%. Stove drying of moulds and cores has been abandoned. **Foundry Experiences with the CO_2 Process.** I. Rees. (305–309). The successful application of this process by Messrs. Glanmorfa Ltd. is described. This jobbing foundry produces castings from a few pounds to 10 tons net in plain carbon steel and up to 20 tons net weight in grey iron. Details of the core assembly methods used to produce large castings are given. The heaviest casting yet produced by the CO_2 process weighed 16 ton 13 cwt. **Foundry Experiences with the CO_2 Process.** C. Blackburn. (310–312). Experiences gained at Messrs. T. H. and J. Daniels Ltd. are described. The process was installed in the foundry within a fortnight. As many cores as possible are now made by the CO_2 process. **Foundry Experiences with the CO_2 Process.** A. Tipper. (313–315). A number of illustrations showing the use of the CO_2 process at Messrs. Harborough Construction Ltd. are reproduced together with descriptions. **Properties and Testing of CO_2 Process Materials.** D. A. Taylor. (316–336). The effects of moisture content and the addition of clay, pitch, coal dust, wood flour and sugar have been investigated. Tests

have been made on reclaimed sands and the effects of reclaimed sands on the CO_2 process itself and on normal moulding sand have been examined. **General Discussion.** (337–362).

Investigation of the CO_2 Process—Factors Influencing Compressive Strength. R. Ziegler and G. Hammer. (*Found. Trade J.*, 1956, **101**, July 19, 85–87; from *Giesserei-Nachrichten*, 1955, May). The effect of a number of variables on the compressive strength of cores made by the CO_2 process were investigated using three different sands and three commercial binders. The variables studied were mixing time, binder content, quantity of CO_2, degree of ramming, storage time prior to gassing, standing time after gassing, and the effect of heating after gassing.—B. C. W.

Consideration of Croning's Shell-Moulding Method in Modern Foundry Technique. F. Pölzguter. (*Giesserei*, 1956, **43**, May 24, 270–280). The principle of shell-moulding, its historical development and the present patent position are first described. The methods and machines used for the manufacture of shell moulds and of hollow cores are described in detail and amply illustrated. Preparation of the moulds for casting is shown and a suggested layout for a mechanized shell-moulding foundry illustrated. Finally, useful examples and the economics of the process are discussed.—R. J. W.

Heavy Metal Casting after Croning in the Jobbing Foundry. M. Lottermoser. (*Giesserei*, 1956, **43**, May 24, 281–285). The use of artificial resins and separating agents in the preparation of moulds by Croning's method is first discussed and the composition of resin–quartz sand mixtures given. The advantages of the use of resin-bonded sands and their manufacture are described and illustrated, together with several methods used to finish the shell-moulds. Tolerances that can be maintained on different castings are given.—R. J. W.

The Phenol-Formaldehyde Synthetic Resins for the Croning Method. W. Büchen. (*Giesserei*, 1956, **43**, May 24, 291–295). The chemistry, classification and properties of phenol-formaldehyde synthetic resins which could be used for the shell-moulding process are described. The raw materials required and the method of manufacturing these resins is also described.—R. J. W.

The Influence of Hydrogen in the Titanium-CO_2 Process. J. V. Dawson, B. B. Bach and L. W. L. Smith. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1956, **6**, July, 249–258). Titanium additions are shown to refine the graphite structure in grey cast iron and the bubbling of a dry, inert gas enhances this refinement. Bubbling hydrogen has an opposite, coarsening effect on the graphite. The part played by sulphur in controlling graphite formation is discussed.—B. G. B.

Experience with Fast-drying Bonding Materials. A. I. Donaldson. (*Found. Trade J.*, 1956, **100**, May 24, 351–359). Experiments on the use of self-hardening fast-drying oil are briefly referred to, and then experiences in making moulds and cores by the CO_2 process are described in detail.

Is Green-sand Moulding Deteriorating? H. Haynes. (*Found. Trade J.*, 1956, **100**, Apr. 12, 167–173). The manufacture of several large castings in green sand moulds is described to show what is possible with the method when it is properly used. The examples chosen are a housing-bed, a large moulding-pit box built up of open sand-cast plates and a bedded-in fly-wheel.—B. C. W.

Making Allowances for Shrinkage in Constructing Models for Steel Casting. W. Lippert and H. Schied. (*Giessereitechn.*, 1956, **2**, Aug., 182–183). Factors influencing the amount of shrinkage are enumerated. Shrinkage can fluctuate from 1·2 to 2·0%. Four practical examples are given to illustrate the amount of shrinkage for which allowance must be made from case to case.—L. J. L.

Production Moulding of Components For Cast-Steel Bogie Trucks. J. G. H. Loubser. (*Found. Trade J.*, 1956, **100**, May 3, 273–280; *Engineer Foundryman*, 1955, **20**, Dec., 56–62). An account is given of the development by the steel foundry of the South African Railways of a method for producing integrally cast steel bogies. The melting techniques used with the cupolas and Tropenas side-blown converters are described, together with the development and organization of the moulding methods.—B. C. W.

Marchagee Bentonite as a Bonding Agent for Synthetic Foundry Sands. A. N. Waterworth. (*Inst. Brit. Found. Australian Branch, Convention* 1955, 11–36). Tests on the Australian material are described with comparisons against U.S. Southern and Western materials. Green and dry compression strength, green bulk density, and permeability were determined with 2–10% clay in sand.

A New Type of Beneficiation of Cement Old Sand from a Cement Sand Molding Shop. W. Pohl. (*Giesserei*, 1956, **43**, Feb. 16, 94–98). The dust separation from old cement sand is first described. The author then describes the Rheax sludge plant for the benefication of old cement sand, with diagrams and photographs. This consists essentially of 4 parts: the dissolver, the vertical sludge apparatus, the horizontal sludge apparatus, and the thickener. These are described separately. It is possible to make plant of this type completely automatic.

Zircon Sands Give Smoother Steel Casting Surface. H. Chappie. (*Western Metals*, 1956, **14**, Jan., 68, 71). Properties of the sands and advantages in use are given.

Molding Sand Properties from Investigations using Large Numbers. H. Reininger. (*Giesserei*, 1956, **43**, Feb. 16, 85–88). This work shows that the extent of heterogeneity in many moulding sand mixtures can only be proved by investigations using large numbers, even in mixtures that are normally supposed to be homogeneous. Examples given include the spread of results on Brinell hardness results and frequency distribution curves for shear strength and gas permeability.

Determination of Humidity of Foundry Sand. (*Fonderie*, 1956, March, 118–120). A review of physical and chemical procedures.

Testing the Dynamic Strength of Mould Mixtures. Ya. A. Smolyanitskii. (*Zavodskaya Laboratoriya*, 1955, **21**, (10), 1236–1237). [In Russian]. In the apparatus described a formed green sample of mould mixture is placed on a horizontal surface which is repeatedly raised and allowed to fall through a distance of 20 mm. The index of dynamic strength is taken to be the arithmetic mean of the number of impacts between the appearance of the first crack and its passage over the whole upper surface. Results obtained show the effect of moisture on the dynamic strength of similarly and differently compacted samples. Deviations from the mean did not exceed 10%.—S. K.

Sand Mould Penetration Testing. I. A Simple Laboratory Apparatus for Estimating the Resistance of Sand Moulds to Penetration by Molten Metal. D. H. Houseman, D. V. Atterton, and T. P. Hoar. (*Metallurgia*, 1956, **53**, Jan., 21–25). The apparatus described allows the measurement of the pressure required to make liquid metal (mercury) penetrate a sand sample removed from a mould face. Some practical results obtained are discussed.—B. G. B.

The Electric Probe—a New Foundry Instrument. Z. Vojtíšek. (*Slévárenství*, 1956, **4**, (2), 46–48). [In Czech]. The principle of short-circuiting by means of molten metals is used as basis of a new apparatus by means of which it is possible to measure the rate of flow of metal through the gating system and the rate of filling of the mould, as well as the instantaneous level of the metal in the mould.—P. F.

The Riser-Pouring Process. A. Holzmüller. (*Giessereitechn.*, 1956, **2**, May, 104–107). A filter core is placed in the riser which is then used for pouring. The filter core rests on the ledge of the riser head until, as the mould is filled, it rises. During the casting process the areas surrounding the riser are treated to delay freezing of the iron. Controlled freezing, and mould and casting techniques are discussed.—L. J. L.

Gating Affects Quality in Production of Steel Castings. H. Chappie. (*Foundry*, 1956, **84**, Apr., 90–93). The design of gating systems to give satisfactory castings and to prevent sand inclusions is discussed. The methods considered are multiple gates, bottom gates, circle gates, and direct pouring into the head.—B. C. W.

Running and Gating of Castings. W. Collinge. (*Found. Trade J.*, 1956, **100**, Apr. 26, 223–231). The running, gating, and feeding methods adopted for a number of iron castings are illustrated and described. The castings are light and medium weight typical of those encountered in the textile foundry industry.—B. C. W.

How to Use Mouldable Exothermic Compounds. J. E. Gotheridge and D. H. Snelson. (*Foundry*, 1956, **84**, May, 150–156). The properties and production of shapes in mouldable exothermic compounds are briefly described. Results are then given of experiments carried out to determine the correct size of risers lined with the exothermic compounds. Both cylindrical and plate castings are considered and graphs are given to show the correlation between the diameter of the feeding head required for a sound casting and the diameter or thickness of the casting. The technique of using the

exothermic compounds and their practical applications are briefly discussed.—B. C. W.

Progressive Mechanization as Applied to Core Making in a Production Foundry. C. W. Hockman. (*Gen. Motors Eng. J.*, 1956, **3**, Jan.-Feb., 2–9). To cope with the increasing demand on the core shop in an iron foundry, two automatic core blowers were installed. An illustrated description is given of the machines and of the various core boxes in use, together with illustrations of some of the cores produced. Details are also given of the operation of these core blowers and of various modifications made to eliminate unnecessary maintenance time.—E. A. C.

CO_2 Hardening of Cores. E. Magder. (*Canad. Metals*, 1956, **19**, June, 40–44). The hardening of cores and mould sands by this process at the Soil Pipe and Fittings Ltd. grey iron jobbing foundry at Toronto, Canada is described. The results obtained have been very satisfactory.—B. G. B.

Foundry Headaches are being Cured by CO_2. P. Trippe. (*Metalworking Prod.*, 1956, **100**, Jan. 20, 93–97). The CO_2 process, which is a method of producing cores and moulds with a hard bond, simplifies operation of a mechanized or semi-mechanized track instead of core ramming by hand. It can be used for all types of castings from a few ounces to several tons in both ferrous and non-ferrous metal.—M. A. K.

Hardening of Cement Sand Cores and Moulds with CO_2. Part I. H. G. Levelink. Parts II and III. J. P. G. Bruschke. (*Metalen*, 1956, **11**, Aug. 15, 322–326). [In Dutch]. Laboratory experiments having shown that cement sand hardens fairly quickly when treated with CO_2, the method has been extended to practical conditions successfully. With the help of one or two core boxes continuous production of heavy cores has been achieved. The methods of introducing the gas into the cores are described in the latter two parts of the article.—F. R. H.

Cure Cores With CO_2—In Seconds. P. M. Unterweiser. (*Iron Age*, 1956, **177**, Apr. 12, 95–98). The process and applications of curing cores by carbon dioxide are described. The sand contains sodium silicate and shapes are cured in the core box by injecting the gas for about 15 seconds. Use in the foundry of Worthington Corp., which makes 3–10 lb cores for water meter components in bronze, is described.

Progress With the CO_2 Process in British Foundries. A. Tipper. (*Found. Trade J.*, 1956, **100**, Feb. 2, 99–105). The present position of the CO_2 process in British foundries is discussed. Among the aspects considered are the binders available, sand preparation, sand additions, gassing procedures and equipment, properties of the gassed sand, costs and economics, and the re-use of sand.—B. C. W.

The Rationalisation and Mechanisation of Moulding Practice. H. Kühne. (*Giessereitechn.*, 1956, **2**, May, 99–104). The following suggestions are made: the use of pneumatic rammers, sub-division of production procedures, improvement of transport and in sand supply to moulding shops, mechanical casting, new moulding processes. The amount of physical effort demanded by various operations is shown in a diagram.

Shell Mould Job Shop Makes Variety of Castings. R. H. Herrmann. (*Foundry*, 1956, **8A**, Feb., 78–83). A description is given of the equipment and foundry practice used in the mechanized shell moulding foundry of Shell-Cast Alloys Ltd., Guelph, Ont.—B. C. W.

High Frequency Driers and Artificial Resin Cores in the Foundry. E. Walther. (*Giesserei*, 1956, **43**, Mar. 1, 109–112). The basis for high frequency core-drying methods is first described. Technical aspects of plant are discussed, followed by a description of the use of cellulose and synthetic resin core binders. A cost comparison is made between the usual methods and these new methods of core drying. In discussing works experience the whole process of core manufacture is described, starting with beneficiation of the sand, and including working the sand, drying and blacking the cores, behaviour during casting, core removal and finally casting and surface quality.—R. J. W.

Sand Mould Penetration Testing. II. A Practical Comparison of the Effectiveness of Sand Compaction by Several Foundry Moulding Techniques. D. H. Houseman. (*Metallurgia*, 1956, **53**, June, 249–252). A mercury penetration tester has been used to compare the effectiveness of sand compaction round a simple pattern by hand, pneumatic, jolt-squeeze, and sand slinger ramming. When a sand mix suited to each moulding is used the sand-slinger achieves the highest degree of ramming in practice—although this is less than very careful and vigorous hand ramming. The jolt-squeeze machine achieves the lowest degree of ramming.—B. G. B.

Rubber-Modified Alkyd Sealers for Castings. O. L. Campbell. (*Mat. Methods*, 1956, **43**, Apr., 130–131). Parlon sealer, which is an alkyd modified with chlorinated rubber, is described.

The Effect of Inserted Parts on the Mechanical Properties of Grey Iron Castings. M. Bednářík. (*Slévárenství*, 1956, **4**, (4), 127–130). [In Czech]. Tests on the welding-on of chaplets and chills used internally are described, and the criteria leading to good welded joints between these and the cast iron are enumerated.—P. F.

Sub-Surface Blowholes in Grey Irons and Their Association With Manganese Sulphide Segregation. W. G. Tonks. (*Amer. Found. Soc. Preprint*, 1956, No. 23). Typical examples are illustrated of the occurrence of a characteristic sub-surface defect associated with the appearance in the defective area of a slag-like material and segregated manganese sulphide inclusions. The results of experiments carried out to study the influence of manganese, sulphur, and pouring temperature on the incidence of the defect are then described in detail. The defect found in production castings could be reproduced in the test castings and it was found that for given Mn and S contents the incidence of sub-surface blowholes increased with decreasing pouring temperature. At a given pouring temperature if a critical value of the product $Mn\% \times S\%$ was exceeded, the occurrence of the blowholes was promoted.

Accident Prevention in Foundries. W. Schumacher. (*Giesserei*, 1956, **43**, May 10, 241–248). The frequency of accidents and the economic aspects of accident prevention are first discussed. Sources of danger in the foundry and corresponding remedies are described in detail in this well illustrated article.—R. J. W.

Technological and Metallurgical Conditions in the Production of Large Castings (Compressor Cylinders). G. Gertz. (*Giessereitechn.*, 1956, **2**, Aug., 172–173). High tensile strength alone will not provide a material suitable for large castings: pearlitic structure is the decisive factor. The formation of the so-called "top discard" is discussed. What matters is not its height, but its shape, which should be so designed as to ensure that the pipe is transverse rather than longitudinal. The use of the "Williams funnel" is advocated. The use of synthetic materials instead of natural sand for cores is also advocated. The calculation of casting times is discussed. The Sipp cast iron diagram is explained.

The Production of Rolls from (Spherulite) Cast Iron Treated with Mg. B. Körös. (*Giessereitechn.*, 1956, **2**, Aug., 174). A survey is presented of the experiments carried out from 1952 to date on this subject. Precautions against light, smoke, and heat are discussed. No re-seeding with silicon is carried out, but the silicon content is kept abnormally high.—L. J. L.

How Castings Can Fill Automotive Turbine Needs. H. Brown. (*Foundry*, 1956, **84**, June, 104–107). The foundry problems that will arise in the production of castings for automobile gas turbines are discussed.—B. C. W.

Steel Castings for Aircraft Challenge the Foundry Industry. H. E. Simmons. (*Foundry*, 1956, **84**, July, 88–90). The inspection and production problems involved in making castings for the aircraft industry are briefly discussed.—B. C. W.

The Shaw Process of Precision Casting. (*Machinery*, 1956, **88**, Feb. 17, 268–275). Overseas applications of the process are described and illustrated. The names of licensees and their products are given.

An Introduction to the Shell Moulding Process. A. S. Ladley. (*J. Jun. Inst. Eng.*, 1955, **65**, Aug., 331–337). The author describes the methods employed in the comparatively recent commercial application of the shell moulding process. The equipment required, productivity, quality of product, and economics are discussed in detail.—M. A. K.

Shell Moulding's Part in Research and Development. C. E. Cotterman. (*Foundry*, 1956, **84**, July, 182–184, 186, 188). The work of the shell moulding section at the Buick Motor Division, General Motors Corp., Flint, Mich., is described. The section carries out research and development work and at the same time produces non-production parts which may be used in the plant.—B. C. W.

Speedy Shell Moulding Saves Machining Time. W. G. Patton. (*Iron Age*, 1956, **177**, Apr. 5, 99–102). The production of cast crankshafts in "ArmaSteel" by General Motors Central Foundry Division is described. The steel contains 0·003% B, added to the charge, and 0·02% Bi, added to the ladle just before pouring; these ensure the desired distribution of

pearlite after annealing. Thick cope and drag shell moulds are resin bonded and backed up by sand. Annealing is for 21 hours at 1750° F. Most of the operation is mechanized and automatic. Compared with forging, the process has advantages in cost, possible designs, and processing.—D. L. C. P.

Crankshafts with a Future. (*Steel*, 1956, **138**, June 4, 117–118). The production of shell moulded pearlitic malleable crankshafts at the Pontiac Co. is described. Considerable machinery is saved compared with forged shafts.—D. L. C. P.

A Study of the Problem of Nucleation in Foundry Practice. R. Mitsche. (*Radex Rundschau*, 1955, (6), Sept., 548–562). Two main groups of nuclei and " anti-nuclei " are described and their effects on the as-cast structure of metals is discussed. Results are reported of tests with superheated aluminium melts in the production of fine-grained castings.—E. C.

Internal Stress in Castings. (*Found. Trade J.*, 1956, **101**, July 5, 19–27). In this second report of the IBF Technical Council Sub-committee T.S.32 previous work is reviewed and experimental results on the internal stresses produced in triangular-grid and disc castings under various conditions are reported. The factors studied with the former were the effects of casting into hot moulds, of cooling the castings to sub-zero temperatures, of structure and of casting size. Cast iron was used for all these experiments. The experiments on cast discs were made with grey-iron, mild steel, and a 30% Cr iron, and the influence of disc thickness was studied. The results of all the experiments are discussed in relation to the phenomena occurring on cooling and the mechanism of internal stress formation. The main conclusion reached is that the principal factor is the temperature difference which arises within the castings on cooling. Methods of reducing these temperature differences are briefly considered.—B. C. W.

Shrinkage Defects in Grey-Iron Castings. I. C. H. Hughes, and J. H. Gittus. (*Found. Trade J.*, 1956, **101**, July 19, 71–83). Previous work on shrinkage defects in grey and nodular cast iron is reviewed and discussed together with the results of experiments carried out at the BCIRA. The variables covered include pouring temperature, the effects of carbon, silicon, manganese, sulphur, and phosphorus, the mechanism of solidification, the influence of inoculation, and the influence of design and gas content. The authors conclude that (i) soundness is affected by the composition of the iron in a way which is not clearly established, (ii) inoculation, melting in contact with coke and coarse graphite structure are associated with a decrease in soundness regardless of composition, (iii) the design of castings has an important effect on their soundness, (iv) raising the pouring temperature of K-bar castings increases the internal porosity and decreases the surface shrinkage, and (v) no single variable can provide a guide to the soundness of a given casting.—B. C. W.

The Fundamentals of Mechanization in Foundry Plants. J. Czikel. (*Giessereitechn.*, 1956, **2**, Aug., 169–170). The terms " productivity of labour " and " mechanization index " are defined. Partial and complete mechanization of transport and engineering in foundries are discussed. Time and motion studies must precede mechanization. Practical examples are given to illustrate the application of mechanization to varying operating conditions.—L. J. L.

Mechanization Doubles Production. K. L. Mountain. (*Foundry*, 1956, **84**, Apr., 118–123). The recently mechanized foundry of the Elliott Co., Jeannette, Pa., is described together with the foundry practice used for the production of a wide range of iron castings.—B. C. W.

Highly Mechanized Line Produces Enamelware Castings. W. G. Gude. (*Foundry*, 1956, **84**, July, 68–73). A description is given of the new highly mechanized production line at the Chattanooga, Tenn., Division of the Crane Co. which is used for the moulding, pouring, shake-out, and cleaning of bathtub castings.—B. C. W.

Some Aspects of Foundry Quality Control. H. Thomas. (*Inst. Brit. Found. Australian Branch, Convention* 1955, 1–9). Under the headings of Inspection, Records, Administration, Specifications, Design, Raw Materials, and Casting Salvage a review is presented with special reference to the smaller foundry.

Foundry Dust. W. B. Lawrie, A. T. Holman, and F. F. L. Morgan. (*Found. Trade J.*, 1956, **101**, Aug. 9, 129–136). A new low volume high-velocity local exhaust system is described and its applications to a pneumatic chisel, a surface grinder, a portable grinder and a transverse swing-frame grinder are discussed and illustrated.—B. C. W.

Good Foundry Lighting is a Production Tool. F. E. Mueller. (*Foundry*, 1956, **84**, Sept., 108–113). The reasons why foundries require good lighting are summarized and a series of questions are posed to enable the adequacy of a lighting system to be assessed.—B. C. W.

How to Evaluate Foundry Lighting Systems. F. E. Mueller. (*Foundry*, 1956, **84**, Oct., 116–121). The available light sources are described and the factors to be considered in choosing a lighting system are discussed. For illustrative purposes the method of developing a core-room lighting system is analysed. Factors to be considered in appraising lighting equipment are summarized and the economics of lighting maintenance are briefly discussed.—B. C. W.

VACUUM METALLURGY

The Present Position of the Industrial Vacuum Melting Process. O. Winkler. (*Z. Metallkunde*, 1956, **47**, Mar., 133–144). A general survey is made of the effect of treating fluid metal under reduced pressure, and the present fields of application of the process are indicated. Industrial plant using the process is described, including the method of casting, under reduced pressure, metal which has been produced by normal techniques. Economic possibilities are discussed.—L. D. H.

Furnace for Vacuum Heat-treatment of Metals. E. N. Marmer. (*Metallovedenie i Obrebotka Metallov*, 1955, **1**, (6), 36–40). A furnace to take charges up to 10 kg and for temperatures up to 1100° C is described. The minimum pressure is 0·0004 mm.

High-Vacuum Induction Furnaces. (*Brit. Engineering*, 1956, **39**, Oct., 132–133). Details are given of furnaces available from Efco-Edwards Vacuum Metallurgy, Ltd., for vacuum melting of metals and alloys for research and production. Improved characteristics and better yields are obtained for rare metals, high-duty alloys and more conventional materials such as tool and bearing steels. The furnaces are available in 28-lb and 56-lb sizes, requiring 36 and 64 kW, respectively.—K. E. J.

REHEATING FURNACES AND SOAKING PITS

Experiences in the Heating of Steel. W. Trinks. (*Indust. Heating*, 1956, **23**, June 1221–1226). The author deals with American practice concerning rates of heating alloy steel billets. It appears that German practice on which a previous article was based used unnecessarily slow rates of heating. The reasons for the divergencies in practice are discussed.

Application of Tunnel Type Furnaces to Steel Mill Use. J. T. Cook and D. R. Baker. (*Iron Steel Eng.*, 1956, **33**, June, 100–111). Billet heating furnaces are described and tunnel-type annealing furnaces. Details of heating and combustion features are given in a second part.

Heating Heavy Sections—How Fast? Q. M. Bloom. (*Iron Steel Eng.*, 1956, **33**, July, 66–77). Rapid die-block heating is reviewed and heating curves are given for large sections. Furnace design and lay out are considered.

Tonnage Heating by Induction. M. C. D. Hobbs and R. S. Segsworth. (*Iron Steel Eng.*, 1956, **33**, Aug., 125–131). Installations are described and the processes discussed. An appendix relates effect of soaking to rolling characteristics, roll pressure and roll wear.

Scaling of 18-8 Stainless Steel in Reheating Furnace Atmospheres. J. O. Edström. (*J. Iron Steel Inst.*, 1957, **185**, April, 450–466). [This issue].

Exposure of Shrinkage Cavity during the Reheating of Open Top Killed Steel Ingots. L. J. Trilli. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Sept., 1199–1200). The author has investigated the considerable differences in cleanliness in the pipe cavity of open-top N.E.U. killed steel ingots. He concludes that blowholes which form in the solidified top crust may be exposed in the soaking pits, thus providing access for oxidizing gases to the shrinkage cavity.—G. F.

Cooling by Evaporation of Heating Furnaces used in Rolling Mills. S. M. Andon'ev, B. I. Birman, O. V. Filip'ev and Yu. I. Tseluiko. (*Stal'*, 1955, (12), 1129–1135). [In Russian]. It has been decided to introduce cooling by evaporation for cooled portions of many heating furnaces in the U.S.S.R. The present report gives an account of comprehensive work on the theoretical and practical aspects of this system applied to rolling-mill furnaces. The suitability of the system for

furnace vertical and horizontal skid tubes has been demonstrated experimentally and design data for ensuring adequate circulation are given. The circulating water is best introduced from the continuous heating zone side. Empirical correction factors for increasing the accuracy of circulation calculations are given.—S. K.

Study of Scales Formed on Ingots. J. Moreau. (*Rev. Mét.* 1956, **53,** Sept., 703–714). Structure of scales formed on mild rimming steels before and after reheating in soaking pits has been studied by optical microscopical, X-ray and chemical analyses. Before passage into the soaking pits the ingot skin consists of a non-metallic layer composed of a matrix of iron and manganese silicates and aluminosilicates in which some iron can be found. After the soaking pits, the scale is composed of the three iron oxides and scattered amounts of fayalite. The practical implications of the presence of fayalite are considered to be of importance.—B. G. B.

Operators Look Into Hot Furnace—Via TV. (*Iron Age*, 1956, **178,** July 12, 75). The use of closed circuit television on reheating furnaces and a roller table is described. A camera looking into the exit end of a reheating furnace allows the operator accurately to position the end slab, so that it is fully in the heating zone.—D. L. C. P.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Some Effects of Heat-Treatment and Microstructure on the Transition Temperature of a 0·24% Carbon Steel. G. Burns and C. Judge. (*Rev. Mét.* 1956, **53,** 510–521). The relationships between transition temperature in a notched bend test, microstructure and thermal history have been examined for ½ in. plate of 0·24% carbon mild steel. Austenite grain size at the beginning of cooling is shown to be a major factor affecting the transition temperature. Cooling rate also has a substantial effect which is more marked during the transformation of pearlite than in other parts of the cooling range.

Shaker Hearth Furnace Installation Features Flexibility. (*Steel Processing*, 1956, **42,** Sept., 529–530). A new installation capable of handling 200 lb of parts an hour is described and the layout illustrated.—A. H. M.

Heat Treating Superstrength Steels. L. M. Stanton. (*Steel*, 1956, **138,** June 18, 150–151). An electrically heated hardening furnace used at Douglas Aircraft Co. Inc., Calif., for heat treating steels to tensile strengths of 260,000 to 280,000 p.s.i. is described. The parts must be finish machined prior to heat treatment to preserve the finish, and the atmosphere has to be very carefully controlled so as to be neither carburizing nor decarburizing. The working zone of the furnace is 4 ft diameter, 10 ft high.—D. L. C. P.

Application of Electronic Induction Heating Equipment. H. G. Carlson. (*Indust. Heating*, 1956 **23,** Feb., 250–262, 430; Mar., 490–502; April, 751–762). The fundamentals of design of equipment for induction heating is discussed. Coil design, power requirements, matching of load and circuits for generators and power controls are dealt with.—A. D. H.

A New Method of Electrode Control Using Magnetic Amplifiers. W. Kafka. (*Stahl u. Eisen*, 1956, **76,** Apr. 5, 381–390). The author refers to previous methods of control and discusses the object of the new development. General considerations relating to the use of magnetic amplifiers are set down, and the construction of the new control is described. Characteristics of the control in application to furnaces are discussed.

Thermal Treatment of Pinions for Automobiles and Motors. E. Progneaux. (*Rev. Univ. Min.* 1956, 9th series, **12,** Sept. 359–368). Factors contributing to the deterioration of steel pinions in service are discussed. The influence of various forms of heat treatment on the resistance of steel pinions to failure is considered in detail.—B. G. B.

Birlec Plant at E.N.V.: New Furnace for Continuous Gas Carburizing. (*Iron Steel*, 1956, **29,** Sept., 423–425). Details are given of the layout, operation, and metallurgical control of the plant. Its output exceeds 40 tons per week.—G. F.

Reduce Gear Distortion with Mass Marquenching. E. A. Schoefer. (*Iron Age*, 1956, **178,** July 19, 107–109). The advantage of a new heat treating installation are described. Gears, pins, and shafts are case-hardened and quenched. Marquenching in oil at 400° F followed by air cooling has given freedom from distortion and improved toughness and wear resistance. HT alloy work-trays have good life in spite of severe thermal and chemical conditions.—D. L. C. P.

A Dislocation-Attraction Model for the First Stage of Tempering. B. S. Lement and M. Cohen. (*Acta Met.*, 1956, **4,** Sept., 469–476). A dislocation-attraction model proposed for the first stage of tempering is used to calculate the time exponent and the activation energy. The results agree with previous kinetic data for the time exponent but it appears that the activation energy is 50% greater for martensite than for ferrite.

Interchange Induction Coils to Meet Job Needs. D. H. Otto. (*Iron Age*, 1956, **178,** July 26, 66–68). Induction heating is described and advice on coil design is given.

Chromium Diffusion and its Application to Sheet-metal Parts. R. L. Samuel and N. A. Lockington. (*Sheet Metal Ind.*, 1956, **33,** July, 447–454). The authors define the position of diffusion processes in relation to other surface treatment methods. Cr-diffusion is mainly applied to mild steel, and data on resistance to wet corrosion and thermal oxidation are quoted. Conditions of treatment and physical properties of Cr-diffused sheet metal parts are discussed.—A. H. M.

Phospho-tungstic Acid for Hard-Chromising Castings for Aeroplane Motor Segments. F. Lopez Mezcua and V. Bello Vivar. (*Inst. Hierro Acero*, 1956, **9,** Apr.-June, 619–625). [In Spanish]. Details are given of the trial results of 1 g/l additions of phosphotungstic acid to the classical type of industrial chromium plating baths. The optimum conditions for the grey cast iron parts are given as 4 h in a 50 l. bath at 60° C with a c.d. of 95–100 amp/dm to give a bright plate, 0·105–013 mm thick, of 820 to 960 V.D.H., and compare favourably with the classical bath. The microstructures of these plates are illustrated and the advantages of the process are discussed. Bath composition control is discussed and a method for the simultaneous determination of sulphuric and phosphotungstic acid is described. (11 references).

Sulphidizing of Grey Iron and Steel. I. M. Engalychev and P. U. Zemskov. (*Vestnik Mashinostroeniya*, 1956, **36,** (2), 46–48). Cylinders of cast iron, tool steel and grades 20 and 45 steel (0·2% and 0·45% C) and piston rings and other objects were tried in various sulphidizing baths and the products compared with tinned, oxidized, and phosphated specimens. Thickness of coating was measured and wear resistance was investigated on a sliding friction device and on the rings in service. Bath compositions for tools are given.

Temperature-Time Relationships in Hardening of a Molybdenum–Vanadium–Tungsten High-speed Steel. K. Bungardt and R. Oppenheim. (*Stahl u. Eisen*, 1956, **76,** May 31, 689–700). Tests on a high-speed steel containing about 5% Mo, 2% V, and 6% W are described. The effects of hardening temperature and time on carbide solution, grain growth, residual austenite content, hardness, annealing quality, impact properties etc., were investigated. Results are given and discussed.

The Ageing of Steel. G. d'Huart. (*Mét. Constr. Mécan.*, 1956, **88,** Apr., 339–345). The age-hardening of steel by heat treatment and by deformation is reviewed and the practical importance discussed.—B. G. B.

Automatic Selective Hardening of Steel Brake Shoe Webs. (*Indust. Heating*, 1956, **23,** Aug., 1597). A machine for automatic flame hardening of brake shoes near the perforations is briefly described.

Electrospark Surface Hardening of Machine Parts. A. V. Polyachenko. (*Vestnik Mashinostroeniya*, 1955, **34,** (7), 65–70). A method of sectioning is described, and depth of hardened layer was determined as well as microhardness. Steels and grey cast iron and a case-hardened steel were tested with sintered carbide electrodes of 7 kinds. Sparking conditions are given and the structures obtained are described. Previous hardness tests have shown a wide range of values and the explanation is given here. Factors involved in the process are considered and the effects described. Service tests on hardened cams were carried out to confirm laboratory findings and showed satisfactory resistance to wear.

Superficial Thermal Treatment of Teeth by High Frequency Heating. P. Partiot. (*Rev. Univ. Min.* 1956, 9th series, **12,** Sept., 376–382). A detailed review of the application of high frequency heating to the thermal treatment of the surface of gear teeth is presented.—B. G. B.

The Surface Hardening of Steels. J. Reboux, (*Rev. Gén. Mécan.*, 1956, **40,** July-Aug., 275–284). Induction and flame hardening techniques are first described. The development of surface hardening methods in the U.S.A. is considered and recent developments in France are also described. Electronic

equipment specially designed for the induction hardening process is reviewed.—B. G. B.

Commercial Bright Hardening of Stainless Steels. F. Hunter. (*Steel Processing*, 1956, **42**, June, 347–349). A high temperature, controlled atmosphere, muffle furnace is described. Examples of processing cycles are given and advantages and savings are illustrated.—A. H. M.

Induction Hardening as a Means of Increasing the Resistance to Wear of Internal Combustion Engines and Machinery. G. W. Seulen. (*Metal Treatment*, 1956, **23**, Aug., 305–310, 314). The principle of induction heating and the way in which it may be used for the purpose of surface hardening is surveyed; also the influence of the electrical data and the properties of the material to be hardened are briefly considered. The different hardening processes are discussed showing how the shape of the workpiece decides to a large extent the process to be applied.—A. H. M.

The Heat-treatment of Carbon Tool Steels. A. G. Gardner. (*Machinery*, 1956, **88**, Feb. 17, 276–278). Steels containing 0·7, 0·8, 0·9, 1·0, and 1·1 C are briefly considered and soaking times and annealing and quenching temperatures tabulated. Tempering is mentioned.

Huge Car-type Furnace of Adjustable Length for Heat Treating at Temperatures up to 2200° F. (*Indust. Heating*, 1956, **23**, July, 1388–1392, 1532). A natural gas-fired furnace for annealing tanks etc. is described. The furnace is 86 ft long, 16 ft wide and 16½ ft high and is provided with two cars. Half the furnace can be closed off when small parts are being treated. Details of burners and temperature control are given.—A. D. H.

Batch Type Strip Annealing Furnaces—Multiple and Single Stack. C. F. Olmstead. (*Indust. Heating*, 1956, **23**, May, 1010–1020; June, 1201–1216, 1230–1232, 1236). An historical account is given of the development of batch type annealing furnaces for flat strip and coil. Electric, radiant tube and direct fired types are described.—A. D. H.

British Furnace Equipment in Holland. (*Brit. Engineering*, 1956, **39**, Aug., 61). Details are given of the design and testing of an electric furnace for annealing, hardening and tempering of steel bars supplied by G.W.B. Furnaces, Ltd., to Koninlijke Nederlandsche Staalfabrieken. Carbon and low-alloy steel bars up to 21 ft long and from ⅜ to 6 in. in diameter are treated, the maximum charge weight is 5 tons. An additional heating zone can be added to provide controlled cooling.—K. E. J.

Some Aspects of the Flame Tempering of Teeth. H. W. Gronegress. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Sept., 368–376). The increase in the wear resistance and strength of the teeth of gear wheels as a result of flame hardening is discussed. Details are given of typical treatments and of equipment. (13 references).—B. G. B.

Metallurgical Aspects in the Design and Operation of a New Continuous Annealing Line. A. F. Mohri. (*Blast Furn. Steel Plant*, 1956, **44**, Sept., 1043–1047; Oct., 1175–1178). An installation at the Steel Company of Canada, Hamilton, was fitted with a thermocouple and recorder system for the solution of problems arising and the investigation of the effects of the various variables on the annealing process. Test strips were put through a cycle and examined, details of the treatment being recorded. Soaking time, annealing temperature, ageing effects, cooling time, and composition are all discussed and conclusions presented. Relationships were calculated between variables and confirmation found. Hardness is the principal characteristic considered.

Quenching as a Heat Transfer Problem. V. Paschkis and G. Stolz, jun. (*J. Met.*, 1956, **8**, Aug., Section 1, 1074–1075). The authors indicate that the heat transfer from the surface of a quenched body to the quenchant largely defines the resulting hardness. Quenches have been carried out to investigate the influence of several variables on boundary conductance and rate of cooling, and the results are summarized.—G. F.

Heat Treating Retaining Rings for Jet Engines. A. G. Portz. (*Indust. Heating*, 1956, **23**, May, 985–992). Details are given of the fabrication, quenching and tempering of welded retaining rings. 7–40 in. O.D. in gas-fired furnaces.

Deep Salt Bath Furnaces Employed for Martempering Aircraft Weldments. (*Indust. Heating*, 1956, **23**, May, 960–964). A submerged electrode salt bath 4 ft square and 15 ft 6 in. in depth used for martempering welded SAE-4330 steel is briefly described.—A. D. H.

FORGING, STAMPING, DRAWING, AND PRESSING

Cleveland Hardware and Forging Operating Hammer New in U.S. (*Steel Procsssing*, 1956, **42**, Sept., 514–515, 531). A description of a 5000 lb Eumuco chain lift, high-speed drop hammer with variable stroke control is given. Parts produced by this unit and others, of up to 20,000 lb falling weight, are illustrated.—A. H. M.

Use of Heated Compressed Air in Forging Hammers. F. C. Evans. (*Metal Treatment*, 1956, **23**, Feb., 49–54). The economic advantages of using heated compressed air in forging hammers are discussed. Two different designs of compressed air heaters suitable for industry are described, and practical results of their application are given.—A. H. M.

Forgings for the Motor Industry. A. J. Wyatt. (*Metal Treatment*, 1956, **23**, Jan., 29–38). The quality of drop forgings for the motor industry and the means by which metal economy might be improved are discussed from the customers' point of view. The need for closer tolerances and for better co-operation between the drop forger and his customer is indicated.

Position of Scientific Knowledge with Regard to Hot Forming and Forging. E. Siebel. (*Stahl u. Eisen*, 1956, **76**, Apr. 5, 393–397). The most important hot forming processes are reviewed. The author discusses mean tensile strength, stresses, the laws of constant volume and of flow, work of deformation, temperature rise with deformation, and shaping losses. Properties of materials for various conditions of working are given in the form of curves. The practical significance of scientific considerations is discussed.

Design Dies Today: Start Stamping Tomorrow. C. B. Moore. (*Iron Age*, 1956, **177**, Apr. 19, 99–102). The production and applications of steel ruler, dinking or "cookie cutter" dies are described. The shaped steel strips are inset in a ¾ in. plywood dieplate, and used to stamp metals up to ¼ in. thick. Advantages include cheapness, speed, and ease of making a die which may run off over 100,000 steel parts.

Metal Stampings: Some Methods for Saving Material. F. Strasser. (*Iron Steel*, 1956, **29**, July, 343–347). The author discusses strip layout in blanking operations and illustrates the most economical layout for a number of basic stamping patterns. Methods of reducing waste due to scrap allowance, blank shape, strip ends, inadequate subdivision of sheet, and stamping slugs, are considered.—G. F.

Rules for the Design of Stamped Parts. M. Labbaye. (*Mét. Constr. Mécan.*, 1956, **88**, Apr., 385–388). The influence of the design of parts on their ease of production by stamping is discussed.—B. G. B.

Design Techniques for Drawn Parts. F. Strasser. (*Machine Design*, 1956, **28**, Jan. 12, 121–124). Several drawn-part shapes are discussed along with useful design suggestions which should be a guide to the most satisfactory economically drawn components.—M. A. K.

A Study of Forces Required in Tube Drawing. R. Hantos, J. Heeringer and J. Schey. (*Acta Techn.*, 1956, **15**, (1–2), 127–140). [In German]. Works experiments on plug drawing of mild steel tubes with phosphated and lime-coated surfaces respectively showed that friction losses were about the same in both cases. The force acting on the mandrel was found to be 10–20% of the drawing force. Formulæ for the determination of the required pull, given by several authors, were employed, those of Geleji were found to give the best agreement with experiment. Additional lubricants were found to have virtually no effect.—P. F.

Short Mandrels for the Cold Drawing of Tubes with Large Deformations. M. A. Freiberg. (*Stal'*, 1956, (4), 364–365). [In Russian]. The use of short mandrels of VK-15 alloy for the cold drawing of tubes with deformations up to 41·2% with wall-thickness up to 2·5 mm is described. Best mandrel types for tubes of different diameters are discussed.—S. K.

Save with Shaped Wire. (*Steel*, 1956, **139**, July 16, 132–135). Examples are given of how cold-drawn special shapes can be used for a large variety of parts with advantages over other methods of shaping. Particularly useful are slices from shaped wire.—D. L. C. P.

Lubrication in Drawing. E. D. Viers. (*Steel*, 1956, **139**, July 9, 86–89; July 16, 148–152; July 23, 94–98). The need for lubrication is explained and compounds and methods of application given. The essentials of a drawing lubricant are listed and examples of good practice described.—D. L. C. P.

Induction Heating in Tubemaking. S. O. Evans. (*Iron Steel Eng.*, 1956, **33**, June, 75–79). An illustrated account of the Babcock and Wilcox extrusion plant at Beaver Falls, Pa., with special reference to the induction equipment.

Extrusions Solve Problems. (*Steel*, 1956, **138**, May 14, 70–71). Firms extruding steel and other metals in U.S. are noted, and their comments on applications of the products are recorded. Important use is in aircraft parts but the field is spreading and includes tool steels.—D. L. C. P.

Production of Tubes and Shapes from Steel by Extrusion. (*Echo Mines*, 1955, Dec., 785–787). An account of the process as used at Persan is given.

The Production of Extruded Steel Sections. (*Machinery*, 1956, **88**, April 20, 478–490). The application of the Ugine–Lejournet Process employing molten glass as a lubricant is described, together with a new type of billet-heating furnace at the Works of Fiav. L. Mazzacchera, Milan, Italy. The billets are delivered to the Loewy extrusion press of 1150 tons capacity and up to 30 extrusions per h are produced. M. A. K.

ROLLING-MILL PRACTICE

Washington Steel Starts New 52-in. Sendzimir Mill. (*Iron Steel Eng.*, 1956, **33**, Sept., 205–206). A brief description is given.

Modernizing the Hot and Cold Strip Mills at Bethlehem's Lackawanna Plant. F. S. Eckhardt. (*Iron Steel Eng.*, 1956, **33**, July, 55–65). A description of changes in a 79-in. strip mill, constructed in 1935, which increased hot mill capacity over four times and cold mill capacity over eight times.

Rolling Mill for Roofs and Floors. (*Steel*, 1956, **139**, July 30, 96–98). The plant at Inland Steel Products Co. for producing cellular metal roof and floor sections is described. The installation includes: 1. three 120 ft cold roll forming mills handling 12 to 22 gauge coiled galvanized steel strip; 2. an automatic 130 ft welding line; 3. large automatic bonderizing and enamelling plant.—D. L. C. P.

Post-War Modernization of the Sheet Steel Industry in Japan. J. Grindrod. (*Sheet Metal Ind.*, 1956, **33**, June, 404–405). Mainly statistical, but products are briefly reviewed.

Give Sheet Handling a Lift with Magnets. (*Iron Age*, 1956, **177**, June 14, 108–109). Instances where plate or roller permanent magnets were employed to handle sheet steel are given. This method is convenient for heavy sheet steel which is otherwise difficult to handle.—D. L. C. P.

Measurements and Theoretical Evaluation of Roll Pressures and Power Requirements of the Pilger Tube Rolling Mill. A. Geleji, J. Schey, K. Fink, R. Hantos, and F. Köves. (*Acta Techn.*, 1956, 15, (1–2), 205–218). [In German]. Compression specimens fitted with extensometer wire spirals were used.—P. F.

Improved Mill Performance through Modernized Electrical Control. E. B. Fitzgerald and E. Pell. (*Iron Steel Eng.*, 1956, **33**, Aug., 95–102). Improved control of a 38-in. blooming mill is described.

Planning the Conversion of a High-lift Slabbing Mill to a Universal Mill. C. E. H. Morris and R. N. Dale. (*J. Iron Steel Inst.*, 1957, **185**, April, 532–552). [This issue].

The Effect of Reel and Brake Tensions on the Roll Pressure. F. Wiesner. (*Hutnické Listy*, 1956, **11**, (7), 433–437). [In Czech]. On the basis of a mathematical analysis and available experimental results it is shown that Lueg's formula must be modified if it is to give correct roll pressures in the presence of reel and brake tensions.—P. F.

Basic Formulas for Roll Design and Rolling of Alloy Steels. A. M. Cameron. (*Iron Steel Eng.*, 1956, **33**, June, 55–74). After a short section on ingot sizes and shapes numerous roll profiles and rolling schedules are given with an account of round formers and hexagonal section rolling. Former, leader and pass designs for hexagons, octagons, and other shapes are given with specimen calculations and tables of nominal weight per foot and nominal dimensions and plug sizes.

Cast Steel Work Rolls in Hot Strip Mill Finishing Stands. F. H. Allison jun. (*Iron Steel Eng.*, 1956, **33**, June, 98–99). A survey of 30 mills of which 12 use and 10 have tried but have not installed steel rolls.

Computations of Roll Force and Torque in Cold-Rolling by Modern Theory. P. W. Whitton. (*J. Appl. Mech.*, 1956, **23**, June, 307–311). The full theory for the comparison of calculated roll force and torque with experimental values is outlined. This takes into account the strip elastic compression, the derivation of the yield-stress curves in cold rolling and the accurate values for friction coefficient between rolls and strip. The method yields results with an accuracy of $\pm 5\%$.

Increasing the Dimensional Accuracy of Automatic Mill Mandrels. R. P. Zaĭtseva, I. M. Ludenskiĭ and T. S. Shchegol'. (*Stal'*, 1956, (4), 362–363). [In Russian]. The fluctuations observed in the dimensions of mandrels on automatic tube-mills have been studied and measures for eliminating them have been successfully adopted.—S. K.

Optical Instrument for Measuring Camber on Large Rolls. P. W. Harrison. (*Engineer*, 1956, **202**, Sept., 7, 327–329). A device constructed at the N.P.L. for measurements by the interference method is described and illustrated. Rolls up to 25 ft in length and 1–15 ft in diameter can be examined.

Modernization of Working-Roll Bearings in Tube-Rolling Mills. M. Ya. Krichevskiĭ, S. M. Ruvinskiĭ, and I. S. Starets. (*Stal'*, 1955, (12), 1117–1120). [In Russian]. Reconstruction of roll-bearings and gears in various types of mill has shown that the introduction of roller-bearings increases roll stability by a factor of 1·5–2, saving 60–70% lubricant and 10–15% electricity. The use of non-ferrous bearing-metal is avoided and tube quality improved.—S. K.

Selection and Use of Roll Neck Bearings. K. E. McHenry. (*Iron Steel Eng.*, 1956, **33**, Sept., 130–132). Design and materials are briefly considered.

Composition Bearings Used in Rolling Mills. K. E. McHenry. (*Iron Steel Eng.*, 1956, **33**, June, 112–115). Water-lubricated resin-impregnated fabric bearings are discussed.

Review of Industry-Wide Blooming and Slabbing Mill Practices. W. E. Dittrich. (*J. Met.*, 1956, **8**, Sept., 1147–1153). A review is given of the range and variance in blooming and slabbing mill facilities and practices in U.S.A., serving as a standard of comparison throughout the industry. The report deals separately with universal slabbing mills and with blooming mills which roll slabs only, or blooms only, or both.—G. F.

Modernization of Blooming and Slabbing Mills at Sparrows' Point Plant. P. E. Appel and M. Whitmore. (*Iron Steel Eng.*, 1956, **33**, June, 80–93). **Electrical Features.** H. W. Dorset (86–89). **Soaking Pit Improvements.** H. C. Henschen. (89–93). An account of alterations at Bethlehem Steel Co.'s plant. A 54-in. mill was installed and a new 40-in. mill substituted for an old one. Pairs of soaking pits were converted into single large pits by removal of the dividing walls.

Replacement of Inland's No. 2 Blooming Mill. A. L. Schroeder. (*Iron Steel Eng.*, 1956, **33**, July, 130–136). A 40 × 90 in. mill put into operation in 1917 was replaced by a 46 × 100 in. mill with a total down time of 23 days 45 minutes. The planning and process are described.

American Steel and Wire Puts New Cleveland Rod Mill in Operation. (*Iron Steel Eng.*, 1956, **33**, June 141–142).

Rational Roll-Pass Design for Rails. P. A. Aleksandrov and I. S. Trishevskiĭ. (*Stal'*, 1955, (12), 1112–1115). [In Russian]. Various systems of roll-pass design for rolling rails are critcally discussed, with special reference to recently recommended procedure.—S. K.

Expansion at Bethlehem's Saucon Division. Engineering. J. A. Bell. **Construction.** R. L. Willis. **Operations.** R. W. Couch. (*Iron Steel Eng.*, 1956, **33**, Aug., 55–71). The plant produces structural shapes and an illustrated account of new installations is given.

Rolling Balls. S. P. Granovskiĭ, V. I. Efanov, and A. A. Gromov. (*Stal'*, 1956, (4), 333–337). [In Russian]. In the method described, a pair of rolls with parallel axes and having helical ridges whose height gradually increases from one end to the other are used for the production of steel balls for ball mills and roller bearings. The rolls are so arranged and rotated that when a rod parallel to the roll axes is fed into the short-ridge end the ridges take progressively deeper "bites", the final product being spherical. A series of mills for balls of various diameters have been designed and their characteristics are given.—S. K.

Reserves of Productivity of Three-High Sheet Mills. I. D. Kuzema. (*Stal'*, 1956, (4), 331–333). [In Russian]. Increased productivity from a three-high sheet rolling mill can be obtained by replacing the lower cast-iron roll with a steel one. This enables the initial reduction to be increased.

Improved Roll-Pass Design of Rolls for Rolling Section Strip. M. V. Shuralev and S. G. Golega. (*Stal'*, 1955, (12), 1116–1117). [In Russian]. Improved pass design has enabled the productivity of a section-strip rolling mill to be increased by 20–25%, with greater ease of adjustment, decreased rejects and elimination of finishing treatment.—S. K.

Hot Strip Mill at Australian Iron and Steel Limited, Port Kembla. D. Crawford. (*Proc. Australasian Inst. Min. Met.*, 1956, June, 35–51). An illustrated description of this mill is given. The 66 in. hot strip finishing mill consists of 6 stands arranged in tandem and has a maximum finishing speed of 2230 ft/min.—B. G. B.

Power Requirements and Selection of Electric Equipment for Hot Strip Mills. R. E. Marrs. (*Iron Steel Eng.*, 1956, **33,** July, 111–125). Formulæ, tables and curves to simplify selection are presented.

Some Effects of Hot Strip Mill Rolling Temperatures on Properties of Low Carbon Sheet Coils. D. T. Goettge and E. L. Robinson. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**: *J. Met.*, 1956, **8,** Sept., 1169–1174). The authors show that the phase changes occurring in low carbon steel during hot strip rolling are metallurgically significant when related to commonly used temperature control points. This applies particularly to finishing and coiling temperatures, which have an important influence on the level and uniformity of hardness, grain size, and carbide characteristics of the finished hot and cold rolled sheets.—G. F.

Factors Affecting Coiling Temperatures in the Hot Strip Mill. J. G. Sibakin and G. M. Ikeda. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**: *J. Met.*, 1956, **8,** Sept., 1174–1181). Investigations on a 56-in. hot strip mill have permitted the statistical derivation of equations for determining the temperature drop between mill and coiler when using full top and bottom sprays, and top sprays only. A method of estimating the required number and type of sprays for a desired temperature drop is also developed.—G. F.

Another 10,000 Tons of Tinplate. (*Brit. Steelmaker*, 1956, **22,** Apr., 94–97). Design and operating details are given of the new Davy-United cold tandem mill now in production at the Ebbw Vale works of Richard Thomas & Baldwins Ltd. Maximum finishing speed is 5000 ft/min. and maximum strip width is 38 in., with gauge 0·006–0·140 in. Coils more than 16 tons wt. can be handled, and full production would result in outputs of 9–10,000 tons per week.—G. F.

The Sendzimir Cold Strip Mill. M. G. Sendzimir. (*J. Met.*, 1956, **8,** Sept., 1154–1158). The author discusses the evolution of the Sendzimir cold-rolling mill, dealing first with the 1–2–4 combination and then with the 1–2–3–4 combination. Industrial applications are described.—G. F.

Cold Rolling of Stainless Tubes without Cooling. S. S. Shaikevich, N. L. Oslon, P. K. Stasevich, and A. G. Leveinem. (*Stal'*, 1956, (4), 337–342). [In Russian]. It is concluded from test results that the elimination of cooling during the cold rolling of stainless tubes will, under certain conditions, lead to increased productivity and tool life.—S. K.

Development of Automatic Thickness Control for Tandem Cold Reduction Mills. H. S. Maxwell, M. W. Cannon, and R. W. Holman. (*Iron Steel Eng.*, 1956, **33,** Aug., 132–140). Design and construction are described and charts are shown of thickness variations with discussion.

Pipe Mill, Utah. M. P. Klick. (*Iron Steel Eng.*, 1956, Aug., 111–117). A mill producing pipe up to 40-in. diameter is described and illustrated.

Productive and Preventive Maintenance of Finishing Mills. W. C. Whitmore. (*Iron Steel Eng.*, 1956, **33,** Sept., 101–109). The article has special reference to the electrical equipment which is described in detail.

Transistors in the Metalworking Industry. M. W. Cannon. (*Iron Steel Eng.*, 1956, **33,** June, 94–97). Applications to the control of mill drives are described.

A Practical Approach to Coil Splicing. R. E. Morton. (*Iron Steel Eng.*, 1956, **33,** Aug., 118–124). Welding devices are described.

Force and Power Requirements for Hot Shearing of Steel, as Affected by Temperature and Cutting Speed. W. Lueg and H. G. Müller. (*Stahl u. Eisen*, 1956, **76,** July 12, 887–896). After reviewing the mechanics of the shearing process the authors describe experiments in the hot shearing of 50 × 50 mm² bars and 25 × 100 and 50 × 100 mm² plates. Seven steels were investigated in these tests, which were carried out on a 250 metric ton press at temperatures from 700 to 1100° C. The effects of temperature, cutting speed, type of material, the section to be sheared, blade form etc. are discussed by the authors.

Positioning of Machine Dials Decided by Human Eye Observation. R. B. Body. (*J. Iron Steel Inst.*, 1957, **185.** April, 498–500). [This issue].

Study of Industrial Instruments for the Continuous Rolling Mill. M. Oyama and Y. Nozaka. (*Tokyo Univ. Fac. Eng. Annual Report*, 1954, 80–83). Hot strip width gauge, hot strip temperature recorder, X-ray, β- and γ-ray thickness gauges and a wire strain gauge are all described and improvements suggested.

MACHINERY FOR IRON AND STEEL PLANT

Hydraulic Installations in Steelworks. (*Mét. Constr. Mécan.*, 1956, **88,** May, 453–457). A short discussion of the hydraulic equipment installed at a continuous hot rolling mill at the Union Sidérurgique du Nord de la France at Denain is presented. The circulation of water for washing and cooling purposes is included in the discussion.—B. G. B.

Automatic Weighing in the Steel Industry. R. A. Voll. (*Iron Steel Eng.*, 1956, **33,** July, 126–129). The applications of the transducer are described.

Ore Unloading Facilities at South Chicago. W. B. McLean. (*Iron Steel Eng.*, 1956, **33,** Sept., 197–198, 202, 205). A system of 7 new unloaders is described for the discharge of lake boats.

The Brains and Muscles of an Ore Bridge. H. A. Zollinger. (*Iron Steel Eng.*, 1956, **33,** Sept., 181–189). Constant potential and adjustable voltage systems are discussed and factors in design, operation, and maintenance of the latter are considered. Further points are brought up in discussion.

Ore Unloading Bridges for McLouth Steel Corporation. B. R. Baier. (*Blast Furn. Steel Plant*, 1956, **44,** Oct., 1180–1184). Details are given of the construction and operation of two iron ore unloading bridges for this American steel works at Detroit. They are designed to unload ore from ships to the stockyard and to reclaim to receiving hoppers. 12 ton capacity buckets are used and the bridges can unload at the rate of 1054 gross tons/h.—B. G. B.

New Travelling Boom-Stacker. (*Mech. Handling*, 1956, **43,** Sept., 551–556). A stacker for dusty materials such as coal or iron ore, built by Moxey Conveyor & Transporter Co. Ltd., is described and illustrated.

How to Get More for Your Metalworking Dollar—4. Material Handling. (*Iron Age*, 1956, **177,** May 24, 149–164). Advice is given on efficient material handling. Sections are:—1. The right approach, 2. Analysing plant problems, 3. Industrial trucks, 4. Conveyors, 5. Palletizing, 6. Loading and unloading devices.—D. L. C. P.

Cutting up Scrap for the Furnace. (*Engineering*, 1956, **182,** Aug. 10, 180). A new crocodile shear is described, designed by J. Bigwood and Son, Ltd., Wolverhampton.

Increasing Capacity of Ladle Cranes. E. Whitaker. (*Iron Steel Eng.*, 1956, **33,** Sept., 140–147). Rebuilding at Granite City Steel Co. is described. Capacity was increased from 270 to 325 tons and design factors are considered in detail showing how weights and rebuilding were kept to a minimum.

Welded Structures in Cranes and Mill Equipment. I. W. Evans. (*Iron Steel Eng.*, 1956, **33,** July, 105–110). Steel plant equipment is discussed. Welded construction should be designed and neither copied from castings nor left to the welder or fitter.

Preventive Crane Maintenance. R. S. Bogar. (*Iron Steel Eng.*, 1956, **33,** Aug., 84–94).

Crane to Floor Radio. (*Steel*, 1956, **139,** July 30, 106). The use of an FM radio system (" Telecrane ") linking cranes with soaking pits and blooming mills is reported.—D. L. C. P.

A Review of the Structural Steelwork in the " Seraphim " Extensions at Appleby-Frodingham. S. Richards and N. Lancaster. (*Structural Eng.*, 1956, **34,** Oct., 348–359). An illustrated account of the lay-out and of individual buildings, with notes on design and erection, is presented.

Fans for Iron and Steel Plants. R. Jorgensen. (*Iron Steel Eng.*, 1956, **33,** Aug., 141–148).

Remote Control of Equipment over Existing Power Lines. J. W. Bauer, jun. (*Iron Steel Eng.*, 1956, Sept., 148–151). Control of soaking pit covers and cranes are included in a general account of the use of carrier currents.

Short Circuit Protection of Low Voltage Motors and Starters. K. S. Kuka. (*Iron Steel Eng.*, 1956, **33,** July, 78–86). Low voltage power supply in steel mills is discussed.

LUBRICATION

Automatic Processing Aids to Steel Plant Lubrication Problems. S. J. Barber. (*Iron Steel Eng.*, 1956, **33,** Aug., 150, 153). Notes on lubrication are presented.

Rational Organization of Lubrication. T. A. Puzikov and S. M. Nosenko. (*Stal'*, 1956, (4), 352–355). [In Russian]. The special lubricating problems encountered in iron and steel works are discussed and various ways of organizing automatic lubrication are considered in detail.—S. K.

Studies in Lubrication—XI. A. S. C. Ying, A. Charnes and E. Saibel. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78,** April, 465–467). An exact solution is developed for the Reynolds equation in the hydrodynamical theory of slider-bearing lubrication with side leakage for film thickness varying exponentially both in the direction of motion and symmetrically perpendicular to this motion.—D. H.

WELDING AND FLAME-CUTTING

Observations on the Weldability of Plain and Low-alloy Steels. B. Kjellberg, T. Noren and S.-E. Erikson. (*ESAB Revue*, 1956, (1), 1–12; (2), 7–16). Weldability is defined and factors influencing it are considered and the effects on basis metal. A number of low-alloy steels are then considered with methods of testing and results. In the second part, stainless steels and tool steels are considered, the former being classified as martensitic, ferritic, and austenitic and these are considered separately. Effects of tempering, carbide precipitation and intergranular corrosion are referred to and illustrated with micrographs.

Considerations of the Importance of Physical Processes Occurring in the Welding Arc. W. Mantel. (*Schweissen u. Schneiden*, 1956, **8,** Aug. 280–287). The behaviour of the welding arc was examined. It is shown that there are three different types of arc depending on the type of current, and polarity. A consumed tungsten electrode and a consumed, shielded electrode were examined. It is found that a variation in the arc performance influenced the welding process.

Experiments with Carbon Dioxide Shielded Welding of Mild Steel. R. E. Jahn and L. M. Gourd. (*Welding Metal Fab.*, 1956, **24,** Oct., 368–376). It is shown that the choice of the most suitable electrode is governed by both the plate material and the mechanical properties required. An increase in spatter and a poor weld bead appearance was found to occur when using CO_2 instead of argonox 2 in manual welding, and the process is shown to be more suitable for use with mechanical equipment.—U. E.

The Present State of Welding Classifications. H. v. Neuenkirchen. (*Schweissen u. Schneiden*, 1956, **8,** Oct., 374–378). The classification of welding processes is discussed.—U. E.

Economics of Welding Small, Non-critical Pipe. H. A. Sosnin. (*Welding J.*, 1956, **35,** Aug., 796–800). The welding of all-steel pipe, 2½ in. and larger, is discussed.—U. E.

Arc Welding Costs. An Example of Total Production Analysis. A. G. Thompson. (*Brit. Welding J.*, 1956, **3,** Sept., 403–414). The relationships are described between labour cost measured in terms of welding, assembly, and total man-hours, and output measured in terms of weight, length of joint and average plate thickness of product. These relationships and the limits of errors of forecasts based on them for a wide range of sizes of welded products are represented in graphical form and as equations. A practical application is given.—U. E.

Argon Welding of Stainless Steel. W. B. Kilmister. (*New Zealand Engineering*, 1956, **11,** Mar. 15, 93–94). The preparation and procedure for the welding of stainless steel by the argon arc process are described with particular reference to the four grades of stainless sheets available in New Zealand. The relative merits of A.C., D.C., and rectified A.C. electrical systems are discussed.

The Influence of Steel Quality on Oxy-acetylene Welded Thin Steel Sheet. W. Hofmann, R. Müller, and J. M. Sistiaga. (*Schweissen u. Schneiden*, 1956, **8,** Aug., 278–280). Sixteen steels of 0·7 mm thickness were investigated after various deoxidation processes. All showed poor weldability. Some bad alignment was observed with semi-killed and killed steel with 0·07–0·18% Si and in one with 0·47% Si.—U. E.

Design for Welded Constructions of Steelworks. C. H. L. Schneider. (*Schweissen u. Schneiden*, 1956, **8,** Oct., 365–369). The application of welding to blast-furnace assembly, and different types of steelworks equipment is described.—U. E.

Will Preheat Replace Stress Relief. H. J. Nichols. (*Canad. Metals*, 1956, **19,** Sept., 24–26). Examples are given of cases where preheating the base metal prior to welding improves the service of the welded structure to a greater extent than the more conventional welding process followed by heat treatment of the structure.—B. G. B.

Welding High-Pressure Pipe Lines. J. E. Burton and J. N. Bradley. (*Engineering*, 1956, **182,** Sept. 28, 399–404). An account of a new automatic pressure butt-welding process is given in which the plasticity of the steel is used to control the cycle. The prototype and production machines are described and illustrated and portable and shop-production types considered. A further section deals with weld quality and factors and structures are described and shown in micrographs. Development work on high-alloy steels is outlined.

The Behaviour of Electro-Welded High Pressure Turbine Pipe Lines subjected to Internal Explosive Stresses. E. Folkhard. (*Lastechn.*, 1956, **22,** Sept., 137–144). [In German]. This report from Switzerland concerns the behaviour of penstocks under service conditions studied by means of large scale stresses applied by inserting explosive charges internally. Here the influence of the quality of the metal and welding rods before and after annealing the weld seams is investigated. The test results enable an accurate assessment of the safety factors to be made with regard to the different types of pipe. They also provide useful information on the reciprocal influence of the steel boundary area and the weld. From them criteria can also be deduced which can be applied to the installation of penstocks for turbine power plants. Numerous illustrations appear in the text showing the effects of the internal detonations.—F. R. H.

How to Reclaim Plant and Machinery by Practical Welding Applications. G. G. Musted. (*Welding J.*, 1956, June, 560–567). The paper presents some typical examples of maintenance and reclamation problems, especially repairing heavy sections. The use of oxy-acetylene welding and cutting, electric metal arc welding, and the carbon-arc process are discussed.—U. E.

Welded Overlay Rotating Bands. F. W. Hussey and I. G. Betz. (*Welding J.*, 1956, **35,** Aug., 767–775). Rotating bands act as obturators on projectiles and also are engraved by the barrel rifling to impart the spin which provides stability in flight. Bands are derived from overlays deposited directly on the projectile. The inert-gas-shielded metal-arc process was used with the aid of an auxiliary filler wire. Coatings and gas mixtures were explored.—U. E.

Welding and Cutting in Steel Mill Maintenance. R. L. Deily. (*Iron Steel Eng.*, 1956, **33,** Sept., 126–129). Organization and mechanization are discussed in relation to six " essential factors " which may be built into one machine.

The Welding of Type 347 Steels. L. K. Poole. (*AEC–NYO* 3497, 1954, pp. 67. *T.I.D.U. List* 383). The standard 347 electrode has been found not entirely satisfactory for welding and five other electrodes were studied and one of type 3084. Overlay, fillet, restrained butt and horizontal fixed position pipe welds were made. Three gave completely austenitic welds, one was of non-niobium type having a norma ferrite content and the other two were partly ferritic. These gave the most uniform and satisfactory results although other electrodes were better in certain individual tests.

Welding of Type 347 Steels—The Effect of Various Heat Treatments on the Notched-Bar Impact Properties of Type 347 Deposits. L. K. Poole. (*A.E.C.–NYO*–3498, 1954, pp. 33. *T.I.D.U. List* 483). Detailed information is given on impact tests carried out at room temperature and at − 320° F on six welding compositions. They show that austenitic weld deposits are less susceptible to embrittlement when exposed to temperatures of 1100° to 1300° F than are the standard ferritic compositions. The optimum room-temperature impact toughness of all six compositions was determined after heat treating at 1700° F and higher. Impact tests at − 320° F indicate that partially ferritic deposits must be heat treated at 1950° F to ensure a minimum impact value of 15 ft lbs. This value was not attained by any of the fully austenitic type 347 deposits under the test conditions. Type 308L weld deposits show far superior impact strengths,

both at room and low temperatures, except when heat treated within the range 1100–1300° F.

The Welding of 13% Chromium Steels. J. A. McWilliam. (*Brit. Welding J.*, 1956, **3**, Oct., 464–468). The strip lining of mild steel vessels with low-carbon, 13% Cr steels is briefly discussed. Metal-arc welds on these steels were made on $\frac{1}{2}$-in. and $\frac{1}{4}$-in. thick plate, using 25% Cr–17% Ni electrodes. Tensile tests across the welds showed satisfactoty mechanical properties both in the as-welded condition and after post-heat at 750° C.—U. E.

How to Avoid Cracks in Welding Stabilized Stainless. W. L. Fleischmann. (*Iron Age*, 1956, **178**, July 12, 76–78). Causes of cracking at welds in niobium-stabilized stainless steels are considered, and helpful measures are suggested. Cracking may be minimized by (1) using proper techniques in breaking the arc; (2) choosing an electrode composition with a ferrite content.—D. L. C. P.

Electric Welding. Some Notes on Safety Aspects. H. W. Swann. (*Elect. J.*, 1956, **157**, Oct. 12, 1104–1108).

The Effect of Aluminium Additions to Mild-Steel Weld Metal. C. R. Sibley. (*Welding J.*, 1956, **35**, Aug., 361s–368s). Four samples of aluminium-coated steel wire welding electrodes were prepared for evaluation and comparison with bare and copper-flashed electrodes. It was found that the aluminized electrodes produce less spatter and better fillet weld shape than bare and copper-flashed electrodes when carbon dioxide shielding is used. They developed less notch toughness in the as-welded metal and the fracture-transition temperature was increased above that of deposits made with bare and copper-flashed wire.—U. E.

Some Aspects of Low-Hydrogen Electrodes. L. J. Lalor. (*Engineer Foundryman*, 1956, **21**, Aug., 54–56; Discussion, 56–58). A general account is given of the effect of hydrogen in steel and of its effect in welding.—A. D. H.

Characteristics of Electrode Coatings. S. W. Raffills. (*New Zealand Eng.*, 1955, **10**, Oct. 15, 339–342). The purposes and properties of electrode coatings are discussed and the classification of coatings in BSS 1719: 1951 is explained. The characteristics, chemical composition and uses of each class of coating are described.

Thirty Years a Welder. H. Thomasson. (*Canad. Metals*, 1956, **19**, May, 33–36; June, 26–30). Factors affecting the satisfactory welding of metals are discussed and reasons for failures are explained.—B. G. B.

How To Get Better Welds in a Weldable Steel. H. S. Davis. (*Iron Age*, 1956, **177**, Jan., 70–71). Advice is given on welding 'Carilloy,' a low carbon quenched and tempered constructional alloy plate steel.—D. L. C. P.

Weld Rotation and Weld Slope—Two Less Known Terms in Germany. H. Pflug. (*Schweissen u. Schneiden*, 1956, **8**, March, 86–89). The two terms, "weld rotation" and "weld slope" are discussed, and it is proposed to include these in DIN 1912, German Standard.—U. E.

Automatic and Semi-automatic Welding of Cast Steel with Carbon Dioxide as Protective Inert Gas. V. N. Suslov. (*Svarochnoe Proizvodstvo*, 1955, (1), 14–17). A consumable electrode CO_2 shielded welding process has been rendered semi-automatic, and its variables have now been investigated. The effect of (direct) current strength on weld composition, and the effect of rate of welding are shown and the composition of welding rod most suitable for the process is discussed. Multipass welding and the occurrence of cracks and their elimination are described and the repair of casting defects reported.

Problems of Weld Design and Calculation. K. H. Effertz. (*Schweissen u. Schneiden*, 1956, **8**, June, 187–189). The evaluation of weld seams in steel construction is discussed. The German Standards DIN 4100 and DIN 4114 for welded structures are considered.—U. E.

Problems of Welded Fabrications. J. Ruge. (*Schweissen u. Schneiden*, 1956, **8**, June, 189–193). Problems arising in welded fabrication using gas welding, resistance welding, and automatic welding sets are discussed. The importance of stress relief treatment applied to part only of welded construction is discussed briefly.—U. E.

The Welding of Steels for High-Temperature Purposes. E. Kauhausen. (*Welding J.*, 1956, **35**, July, 347s–356s). Abstract of a paper published in "*Grosse Schweisstechnische Tagung*, 1955, 10–16; F. Vieweg e Sohn, Braun-Schweig, Germany. A list is given of principal steels for high temperature applications in power plant, refineries, and gas turbines.—U. E.

Material Problems of Welding. H. Koch. (*Schweissen u. Schneiden*, 1956, **8**, June, 193–203). The effect of welding method on weldability and its definition are discussed. A list is given of different types of welding methods applicable to the most important light alloys, non-ferrous metals, cast iron, and steel. The physical and metallurgical reactions during fusion welding are discussed in detail and correlated to weldability. The definition "welding safety" is discussed and the effect of the three dimensional state of stress and type of material on welding safety.—U. E.

Simple Procedures for Fusion Welding 17/7 Stainless Steel. T. A. Dickinson. (*Sheet Metal Ind.*, 1955, **32**, Oct., 764–765). An outline is given of the specific welding conditions for the production of sound fusion welds; high welding speed, 17/7 filler rods without flux, flow of argon or helium through torch and back-up bar, and low machine settings to give 100% penetration. It is claimed that welds withstand the same stresses as the parent metals.—A. H. M.

Bibliography on the Welding of Stainless Steels 1926–1955 with Author Index. Katherine Janis. (*Weld. Res. Council, Weld. Res. Council Bull. Series*, 1956, Mar., No. 25, 27 pp.).

Factors Affecting Low-Cost Arc Welding. M. W. Wright. (*Australian Machinery*, 1956, **9**, Jan., 7, 9, 11, 13, 15). A detailed account of design, fabrication, materials and processes from the point of view of economic operation. Types of electrodes are discussed with a view to correct choice and types of joint with regard to strength, speed of welding, and economy in weld metal.

A Selection Guide for Methods of Submerged-Arc Welding. R. A. Wilson. (*Welding J.*, 1956, **35**, June, 549–555). The author gives a review of different types of automatic submerged-arc welding and describes the chief advantages of the different processes and equipment.—U. E.

Arc Welding Costs. An Example of Shop Work Measurement. A. G. Thompson. (*Brit. Welding J.*, 1956, **3**, July, 306–322). The work measurement studies were made by the welding foreman on three welders of widely differing skill in a workshop of a company manufacturing stiffened flat plate containers. The resulting data were analysed according to the procedure of the new technique, which is briefly to graph a measure of cost against a measure of output, analyse the accuracy of the resulting relation, and then improve accuracy for obtaining further data.—U. E.

Shielded-Arc Welding of Unalloy Steel. W. Hummitzsch and F. Mersmann. (*Schweissen u. Schneiden*, 1956, **8**, March, 73–79). The shielded arc welding process when applied to the welding of unalloyed steel is discussed. The use of argon with and without oxygen, and carbon dioxide, and their effects on weld quality is investigated.—U. E.

The Carbon Dioxide Shielded Metal-Arc Welding Process. R. J. Keller, J. Koss. (*Welding J.*, 1956, Feb., 145–151). The necessary equipment, properties of the resultant weld metal and new applications of the process are discussed.—U. E.

Gas-Shielded Consumable-Electrode Welding of 4130 Steel. C. R. Sibley. (*Welding J.*, 1956, **35**, April, 354–340). It was found that standard AISI low-alloy electrode analyses with controlled phosphorus and sulphur contents provide hardenability characteristics in the weld metal similar to those of low-alloy plate material. When carbon dioxide is substituted for argon as the shielding gas a considerable loss in carbon, silicon, and manganese results which produces a weakened weld metal of low hardenability.—U. E.

Fortiweld. A New Development in Weldable High-Tensile Steel. Part III. H. F. Tremlett. (*Welding, Metal Fab.*, 1956, **24**, July, 250–252). Satisfactory mechanical tests on butt welds in 1 in. thick Fortiweld plate, welded by the Unionmelt process, indicate that welding wire to grade 3 and powder to grade 80 are desirable. Good notch-toughness values are obtained for all-weld-metal specimens machined from the joint.—U. E.

Contribution to the Study of the Welding of Austenitic High-Temperature Steels. J. Hochmann. (*Métaux–Corrosion–Indust.*, 1956, **31**, June, 265–273). Arc welding of this type of alloy steel is difficult due to cracks in the weld. Reduction in the silicon content of the welding rod can improve the weld. The results of welding tests carried out on austenitic steels with welding rods of different composition are reported. Factors controlling the formation of the sigma phase are discussed. Welding rods depositing a bead with an austeno-ferritic structure were found the most satisfactory for use with high temperature austenitic steels.—B. G. B.

Welding in Steel Construction. A. Dörnen. (*Schweisstech.*, 1956, **10**, Jan./Feb./March, 32–39). The use of converter steel and O.H. steel for welded steel construction is discussed. Some practical applications are described with illustrations.

Mechanical Properties and Weldability of Six High Strength Steels. R. D. Stout and J. H. Gross. (*Welding Res. Council Bull. Ser.*, 1956, No. 27, May, 1–9). An investigation was made of six high strength steels to determine their suitability for use in pressure vessels with increased design stresses. The six steels have been compared on the basis of room and elevated-temperature tension tests, notch-toughness unwelded and welded, plastic fatigue, and standard weld qualification tests. It was found that the properties of these steels compare favourably with those of carbon steels.—U. E.

Properties of Arc-Welded Joints between Aluminium and Stainless Steel. M. A. Miller and E. W. Mason. (*Welding J.*, 1956, **35**, July, 323s–328s). Argon-shielded tungsten-arc welded joints were tested for tensile, bursting, fatigue, and shear strengths. The effects of post-heating and thermal shock cycling tests are considered and resistance to corrosion is discussed.

Welding of Steam and Feed Pipework for Marine Installations. J. Chamberlain and W. L. Roe. (*Trans. Inst. Marine Eng.*, 1956, **68**, June, 173–192). Types of steel for various temperature ranges are considered and a comprehensive discussion of design, welds, defects, and repairs is given, followed by contributed comments.

Electric Butt-Welding of High-Carbon Steel Wire. W. Wefli. (*Draht, English Ed.*, 1956, June, 46, 48). Welding and after-treatments are discussed with reference to the Probat SP setting press.

The Modern Electric-Weld Steel Tube Mill. F. Spicer (*Metalworking Production*, 1956, **100**, Jan. 13, 63–68). The article describes in detail the design and operation of the Yoder resistance-weld mill, which is in use at Raleigh Industries Ltd. cycle factory at Nottingham.—M. A. K.

New Mill for the Production of Welded Tubes with a Spiral Seam. A. I. Tselikov and A. A. Sarȳchev. (*Stal'*, 1955, (9), 815–820). [In Russian]. An account is given of preliminary work on the production of large diameter spirally welded tubes from coiled strip and of the newly designed, full-scale mill which is now operating. The mill produces tubes 8–18 m long with external diameters and wall thicknesses of 426–630 and 4–8 mm respectively, from hot-rolled carbon-strip 1180–1500 mm wide in coils weighing 1·3–5 tons and having external and internal diameters of 850–1400 and 750-mm, respectively. The general technology of the process is described and the individual items of equipment are considered. Results of pressure tests on the tubes and data on their deviations from required dimensions are presented.—S. K.

It Isn't Mud—If You are Careful. H. F. Reid, Jun. (*Canad. Metals*, 1956, **19**, Aug., 32–35). The influence of the electrode coating on the welding of steels is discussed. Examples of the different types of coating available and the steels with which they are used are given.—B. G. B.

The Problem of Shear Strength of Soldered Joints. H. Kodi and W. Pönitz. (*Schweissen u. Schneiden*, 1956, **8**, Aug., 288–292). The shear strength of soldered joints was investigated and it is shown that the shear test is suitable for determining the static loading capacity of a soldered joint. A dependence is found of the shear strength on the type of solder quality of joint and gap width.—U. E.

Some Dynamic Mechanical Properties of Heat-Treated Low-Alloy Weld Deposits. E. H. Franks and W. H. Wooding. (*Welding J.*, 1956, **35**, June, 291s–297s). The mechanical properties have been determined and are illustrated for low-alloy nickel–molybdenum–vanadium (E100XX) weld deposits in the as-welded, stress-relieved, quenched, and tempered and annealed conditions. It is shown that AWSE10015–16 (Ni–Mo–V) deposits have excellent ductility and show exceptional endurance limits under cycles of reversed stress in both the as-welded and heat-treated conditions.—U. E.

Investigation of the Fatigue Resistance of Butt-Welded Joints in a Spanish Welding Steel of the "Lloyd" Type. Z. Garcia Martin. (*Inst. Hierro Acero*, 1956, **9**, May, 519–535. Special Number). [In Spanish]. Endurance curves for conditions of plane bending and pulsating tension have been determined on specimens of a carbon steel (0·08% C, 0·58% Mn, 0·2% Si, 0·02% P, 0·06% S) with and without the presence of a butt weld (weld metal contained 0·13% C, 0·39% Mn, 0·13% Si, 0·04% P, 0·027% S.). Tests were made comparing unmachined and prepared surfaces and it is concluded, among other things, that (*a*) the steel in the normal constructional state has a smaller fatigue resistance than when its surfaces are prepared, (*b*) the presence of an unmachined weld lowers the fatigue resistance but machining effects a considerable improvement, (*c*) the fatigue limit of the base metal is 82% of the elastic limit for plane bending and 109% for pulsating tension.—P. S.

Practice in Non-Destructive Testing of Welded Tubes. H. D. Weise. (*Schweissen u. Schneiden*, 1956, **8**, Oct., 355–363). The application of X- and γ-ray testing and the ultrasonic method to welded tubes is described. Different types of defects are explained. The defects found by the non-destructive test methods are proved by ordinary metallographic examination. It is shown that the ultrasonic method is less suitable for testing welded tubes, while X-ray examination gives better and more reliable results.—U. E.

Evaluation of Weld-Cracking Tests on Armor Steel. S. Weiss, J. N. Ramsey and H. Udin (*Welding J.*, 1956, **35**, July, 348s–356s). A study was made of the "cruciform", "controlled-thermal severity", and "multiple bead-on-plate" weld-cracking susceptibility tests. Two different heats of alloy armour plate were studied and the cruciform test resulted in under-bead cracking in both heats while none was observed in the other two tests. The rate of cooling of controlled thermal severity test specimen was artificially increased to a high value and cracking still did not occur. It is shown that for these materials the degree of external restraint plays a more important role than thermal severity in causing hard-zone cracks.—U. E.

Examination of Failures in Welded Constructions. W. Marfels. (*Schweissen u. Schneiden*, 1956, **8**, Aug., 269–277). A methodical examination was made of welded failures dividing the fractures into three types: forced tough fracture, forced brittle fracture, and fatigue fracture. Micrographs are given of the three types and their characteristics are discussed.

The Actual State of Development of Braze Welding. L. Fuchs and F. Schott. (*Prat. Soud.*, 1955, **9**, Aug.-Sept., 119–122; Oct., 147–153; Nov., 164–167). A fully-illustrated account of the process and its applications.

Fundamentals of Brazing. N. Bredzs and W. Rostocker. (*PB* 111509, 1953, pp. 115; *T.I.D.U. List* 408). A survey of the significance of joint thickness in limiting the strength of joints, concluding that the choice of alloys was unsuitable. Base and brazing metals not forming intermetallic compounds but not mutually insoluble are suggested, e.g. Fe–Ag, Fe–Cu and possible Fe–AgCu, Fe–AgMn. A reproducible induction-heating method is described and joints are tested and the effects of imperfections discussed. The mechanism of wetting of steel by filler metals is then considered and the effects of atmospheric oxygen shown.

MACHINING AND MACHINABILITY

Machinability Tests. M. van Molkot. (*Microtecnic*, 1956, **10**, (2), 75–79). Machinability tests, from the point of view of the efficiency of the machining operation, were carried out on several types of steel. A constant load drilling test was made by milling with a standardized 12 mm milling cutter a cylindrical test piece already drilled with a hole 10 mm in diameter. Calorimetric planing and milling tests were also carried out. The procedure and results are given in detail in each case.—L. D. H.

Present Knowledge of Machinability of Iron and Steel. F. Rapatz and F. Motalik. (*Stahl u. Eisen*, 1956, **76**, April 19, 477–485). The authors review literature relating to cutting power formulæ, the effect of cutting lubricant on wear, the possibility of estimating wear, administrative considerations in the choice of tool life criteria, the causes and mechanism of wear, the measurement of surface quality, the effect of cutting conditions and material properties on surface quality, the effects of structure, strength, sulphur content and lead content on machinability, the further development of tool materials, test methods, hot machining experiments, the machinability of austenitic steels and metallic sinter components, and suggestions for future research.

Metal Working with Stock Removal and Its Effect on the Condition of the Product. M. Pesante. (*Microtecnic*, 1956, **10**, (1), 26–30). The effect of grinding on internal stresses, resistance to fatigue and improvement in surface finish is considered. Test bars of chromium steel were annealed to minimize internal stresses due to previous machining, heated

to 840° C, quenched in oil, and subjected to controlled grinding operations. It was concluded that grinding, if carried out correctly, does not cause appreciable surface softening; due to the appearance of traction forces in the surface layer, the fatigue limit is lowered. The effect of the quality of the wheel and the grinding cycle on the quality of machining are discussed.—L. D. H.

Influence of Cutting Speed on the Change of Mechanical Properties of Chips from Annealed Steels. M. Rosner. A. Simionescu and C. Ciochină. (*Buletinul Institutului Politehnic din Jași*, 1955, **1**, (1–2), 403–416). [In Rumanian; French and Russian Summaries]. Calorimetric measurements of the mean temperature of chips is given. The method is simplified and can be used over a wide range of cutting speeds. Temperature at the cut is determined thermoelectrically. It is found that above a certain speed the temperature, apart from a very thin surface layer, decreases as the rate increases. The measurements are in agreement with previous work.

Study of High-Speed Machining III, Analysis of Coefficient of Friction in Metal Cutting. H. Takeyama and E. Usui. (*J. Mech. Lab.*, 1956, **10**, Jan., 17–22). Tangential and normal stresses on the tool face were measured and tool–chip contact area measured photomicrographically. At low speed the tangential component depends on contact area and the normal component upon conditions rather in advance of the cutting edge.

Study of High-Speed Machining IV. Analysis of Carbide Tool Wear. H. Takeyama, T. Murai, and E. Usui. (*J. Mech. Lab.*, 1956, **10**, Jan., 23–34). Flank wear and cutting time are plotted on log-log paper giving two straight lines. The slopes and levels can be interpreted. A cast iron and an alloy steel were machined with a variety of carbide tools and the results compared.

Steel Hardness Doesn't Bother the Friction Saw. J. E. Hyler. (*Iron Age*, 1956, **178**, July 26, 72–74). The use of circular-bladed alloy friction saws for steel cutting is considered. Blade design and operating conditions for various types of work are dealt with.—D. L. C. P.

Relations Between the Fibrous Structures of Chips Formed in Machining as Determined by X-Ray Diffraction and the Mechanism of Deformation During Metal Cutting. P. Bastien and M. Weisz. (*Microtecnic*, 1956, **10**, (2), 57–64, No. 3, 122–129). Using the non-filtered radiation of an anticathode of Mo, the principal wavelength of which is $Mo_{K\alpha} = 0{\cdot}7076$ Å, X-ray diffraction studies were made of the fibrous structure of chips formed during machining, with the object of obtaining information on the mechanism of deformation in orthogonal metal cutting. Plain carbon steels, normal and free-cutting, a low-alloy and an austenitic steel were investigated. The authors point out that the geometrical notion of a shearing plane is a first approximation to a shear volume comprising all the envelope surfaces of the active glide planes. The mechanism is shown to be divided into two phases: a phase of uniform compression, directing the metal to a position of stable equilibrium, and characterized by the fact that many glide planes are positioned perpendicularly to the plane of symmetry of orthogonal cutting, and a phase of simple gliding. Solutions proposed in the literature are studied critically.—L. D. H.

Cutting Action of Tools. P. Harris. (*Research*, 1956, **9**, Mar., 109–113). Wood and metal are compared and chip formation described.

An Explanation of the Formation of Groove Wear on Cutting Tools. P. Albrecht. (*Microtecnic*, 1956, **10**, (3), 145–148). Severe wear concentrated on the flank of a high speed tool at a position corresponding to the external surface of the workpiece, and developing into a groove, was found during machining tests. This was analogous to grooves and furrows previously found and reported on carbide tools, no satisfactory explanation having been given. After discussing the mechanism of the groove wear, it is shown that the groove is produced by the movement of the built-up edge material to the outer surface of the work, where it is driven down between the tool flank and the work, and acts as an abrasive.—L. D. H.

Dust Control on Grinding Machines. (*Found. Trade J.*, 1956, **101**, Oct. 4, 393–394). A description is given of the modified dust control system for pedestal grinders (developed by the British Steel Castings Research Association), which has now been approved for universal application by H.M. Chief Inspector of factories.—B. C. W.

Pneumatic Swarf-handling Plant. (*Mech. Handling*, 1956, **43**, Oct., 600–603). An installation of the Standard Motor Co. is described. Suction ducting with cyclones and fabric filters collects swarf from machine shops.

Spark-machining Process. J. L. Adcock. (*Sheet Metal Ind.*, 1956, **33**, Aug., 530–536). A brief comparison is made between electrolytic, electro-arcing, electro-sparking and ultrasonic methods. The principles of spark-machining, the basic circuit used, advantages and limitations are discussed. The versatility of available machines is illustrated by examples: in one, piercing $\frac{1}{8}$-in. dia. ball-bearings with a hole 0·008-in. dia. is executed on a 2kVA machine.—A. H. M.

CLEANING AND PICKLING

Selection of Solvents and Control of Hazards. J. B. Moore. (*Iron Steel Eng.*, 1956, **33**, Aug., 78–83). Cleaning solvents for ironworks machinery are discussed from the safety standpoint.

U.S. Metal Cleaning Process Comes to Great Britain. (*Indust. Finishing*, 1956, **9**, July, 694, 696). The Kolene process for cleaning metals is described. The removal of scale, paint, etc. is achieved by oxidation or reduction during electrolysis in a molten alkali salt bath; the part to be cleaned is made cathodic to remove oxides or anodic to remove grease and paint.—A. D. H.

Electro-Chemical Engineering Company's New Factory at Woking. (*Metallurgia*, 1956, **54**, Sept., 115–117). An account is given of a factory designed to manufacture automatic pickling and plating machines.—B. G. B.

Chain Parts Coloured Twice as Fast. C. E. Johnson. (*Steel*, 1956, **138**, June 11, 116–117). A continuous salt bath furnace is described, which is used for blueing or browning roller chain components. Parts are carried through the bath at over 800 lbs per hour. This process improves appearance and retention of rust-inhibiting oils and waxes.—D. L. C. P.

On the Application of the H_2SO_4–CH_3OH–C_2H_5OH Bath to the Electro-Polishing of Steels. S. Feliu and M. Serra. (*Inst. Hierro Acero*, 1956, **9**, May, 614–617, Special Number). [In Spanish]. This bath is prepared by slowly stirring 100 ml of sulphuric acid (1·84) into 100 ml of absolute methyl alcohol, standing for 1 day then diluting with 600 ml of absolute ethyl alcohol and is used at 0·08 to 0·15 amp/cm² c.d. for 3–5 min at room temperature. A variety of plain carbon, low and high alloy steels were electro-polished in this bath and micrographs of the results are given and discussed. It is concluded that the bath gives excellent results for all conditions of treatment except when large quantities of carbides are present in the low alloy and plain carbon steels. Reasonable polishes can be obtained in the latter cases with aged baths.—P. S.

Wetting Agents in Metal Finishing Processes. W. M. Halliday. (*Product Finishing*, 1956, **9**, March, 50–56). Types of wetting agents are reviewed and examples are given of their use in cleaning and pickling processes. Laboratory evaluation of cleaners is considered.—A. D. H.

Chemical- and Corrosion-Resistant Floors. B. Mohr. (*Corrosion Techn.*, 1956, **3**, July, 227–231). The article deals with corrosion-resisting floor surfaces for pickling rooms etc., provided over suitable load-bearing bases, to withstand the corrosive action of the various chemicals to which they will be subjected. Amongst the types of flooring briefly discussed are: acid-resisting asphalt mastic, rubber latex/hydraulic cement mixtures, acid and alkali-resisting mortars. It is stressed that, apart from corrosion, the type of traffic, ease of renewal, maintenance, etc. must be considered. Attention should also be paid to vibrations affecting the floor, possible settling of the floor, and the live and dead loads to which it will be subjected.—L. E. W.

The Chemical Treatment of Nickel, Nickel-Chromium and Chrome-Iron Alloys Prior to Electrodeposition. E. Morley. (*Bull. Inst. Met. Finish.*, 1956, **6**, (1), 59–61). Anodic oxidation of 14–18% Cr, 0·12% C steel followed by cathodic reduction in a solution of 40% H_2SO_4, 10% HCl gives a surface which is ideal for plating with copper.—A. D. H.

PROTECTIVE COATINGS

Plating. (*Iron Age*, 1956, **177**, June 28, 99–104). This is a study of the efficiency of plating practices, dealt with under the heads:—management; maintenance; layout; product design; water supply, plating wastes.—D. L. C. P.

The Protection of Metals in Railway Service. F. G. Dunkley and W. J. Hair. (*Electroplating Metal Finishing*, 1956, **9**, Mar., 77–81). Methods used by British Railways for preventing corrosion of rolling stock and structures are discussed.

Corrosion Proofing Railway Coaches. (*Corrosion Prevention and Control*, 1956, **3**, Aug., 33–36). The article is divided into two parts which deal with the "Granodising" Process of I.C.I. Ltd., and the "Bonderising" Process of Pyrene Co. Ltd. respectively.—L. E. W.

Surface Finishes for Stainless Steels. K. M. Huston. (*Products Finishing*, 1956, **20**, July, 24–38). Methods for the surface finishing of stainless steels are described. Cleaning mechanical and electrolytic polishing, plating and a blackening process involving treatment in molten sodium dichromate at 750° F for 20–30 min are included.—A. D. H.

Protective Finishing Processes for Screw Threads. D. J. Fishlock. (*Mech. World*, 1956, **136**, Oct., 438–445). A review of plating, painting, passivating, blueing and blackening processes.

Is there a Quantitative Relationship between Hydrogen Overvoltage and the Solubility of this Gas in Metals? M. Smialowski. (*Bull. acad. Polonaise Sci.*, 1956, **4**, Class 3, (1), 43–47). The proton penetration mechanism is used as an explanation of the phenomenon in soft iron cathodes.

The Influence of Polar Organic Substances and Catalytic Poisons on Hydrogen Overvoltage on Nickel and Iron Cathodes. W. Palczewska. (*Bull. Acad. Polonaise Sci.*, 1956, **4**, Class 3, (1), 37–42). Dibenzyl sulphoxide was studied in N sulphuric acid by means of polarization curves.

An Attempt to Elucidate the High Pressures of Hydrogen in Iron Cathodically Saturated with Hydrogen. K. Guminski. (*Bull. Acad. Polonaise Sci.*, 1956, **4**, Class 3, (4), 227–232). The gas is assumed to penetrate in the form of protons.

A Guide to the Selection of Ion Exchangers for Applications in the Plating Industry. I. M. Abrams. (*Plating*, 1956, **43**, Aug., 1012–1017). Ion exchange resins are classified and the actual and potential uses of each type are explained with reference to the plating industry.—A. D. H.

Planning—Can Reduce Waste Treatment Costs. F. L. Neff. (*Plating*, 1956, **43**, Aug., 1008–1011). Factors affecting the choice of a method for alkali chlorination to detoxify cyanide waste liquors is considered with special reference to continuous methods of treatment.—A. D. H.

The Treatment of Metal Plating Wastes at Sperry's Gainesville, Florida Plant. F. A. Eidsness and P. B. Bergman. (*Plating*, 1956, **43**, Aug., 1005–1007). The removal of Cu^{++}, Ni^{++}, Ag^{+} and CN^{-} from plating wastes is accomplished by using ion exchange resins. Demineralized water so produced is returned to the plating shop.—A. D. H.

Profitable Recovery of Plating Wastes by Reconcentration of Reduced Volume Rinses. K. Odland and J. C. Hesler. (*Plating*, 1956, **43**, Aug., 1022–1025). By using the minimum amount of wash water, evaporation of plating rinse liquors can often be used to recover drag out losses. Applications of the technique to the recovery of metallic cyanides and chromic acid are compared with other methods.—A. D. H.

The Ohio River Valley Water Sanitation Commission. (*Plating*, 1956, **43**, Aug., 1026). The activities of an organization concerned with the prevention of river pollution by metal finishing concerns are briefly considered.—A. D. H.

Precipitation and Filtration. H. M. Small and W. C. Graulich. (*Plating*, 1956, **43**, Aug., 1018–1021). The advantages of precipitation and filtration as a method of disposing of industrial effluent are explained and the equipment and methods are described.—A. D. H.

The Effect of the Catalytic Ion in Obtaining Crack Free Structures in Chromium Plating. H. L. Kee. (*Indust. Finishing*, 1956, **9**, March, 426–430). Doubt is cast upon the value of baths and processes advocated for plating on iron. Adhesion was found to be generally poor and micro-cracks always to be present.

A Minimum Destruction Test for the Adhesion of Hard Chromium Deposits. A. Chessin and J. G. Poor. (*Plating*, 1956, **43**, July, 913–915). Observation of the indentation produced by a small spherical tungsten carbide indenter is used to assess the adhesion of hard chromium plating on ferrous metals.

Bright Nickel Plating. J. R. Bellobono. (*Metal Finishing J.*, 1956, **2**, Sept., 309–313, 316). A detailed historical review is made of the development of baths for bright nickel plating; compositions are given.—A. D. H.

Levelling in Bright Nickel Plating Solutions. K. E. Langford. (*Electroplating Metal Finishing*, 1956, **9**, Feb., 39–43, 48; Mar., 71–76). The relation between the efficiency of organic compounds as levellers in nickel plating and their chemical constitution is investigated. The beneficial effect of wetting agents is explained and nitrogen is shown to be present in such deposits. The analytical control of solutions containing quaternary alkyl derivatives is discussed.—A. D. H.

Tin and Tin Alloy Plating. J. W. Price. (*Metalen*, 1956, **11**, Aug. 31, 351–354). Bath compositions for tin plating are briefly reviewed and then alloy plating is discussed in outline. Copper, zinc and nickel alloy plating are considered and lead, cadmium and antimony referred to.

Possibilities for Tin in Russia's Industrial Expansion. (*Tin*, 1956, Aug., 163–166).

Deposition of Titanium from Titanium-Oxygen Alloys on Copper, Iron and Mild Steel. S. T. Shih, M. E. Straumanis and A. W. Schlechten. (*J. Electrochem. Soc.*, 1956, **103**, July, 395–400). A method for coating iron and steel sheet with titanium was developed. It involved embedding the part to be coated in a mixture of sodium or potassium chloride and titanium fines or titanium alloys containing 5–20% O and heating in helium at 1000° C for several hours. The thickness of the coating depended primarily on temperature but also on time, oxygen content of the alloy and composition of the salt bath. The coatings were adherent, protected the metal from acid attack and were reasonably ductile.—A. D. H.

Processing of Gramophone Record Matrices. C. H. Rumble. (*Bull. Inst. Met. Finish.*, 1956, **6**, Summer, 143–162). Iron electrodeposition is included.

Oxidising and Phosphating Practice in the U.S.S.R. H. A. Holden. (*Electroplating Metal Finishing*, 1956, **9**, Sept., 291–292). Russian methods for oxide treatments and phosphating are briefly reviewed and show that the practice is similar to British and American. A new oxide–phosphate process combining the advantages of each is described. The bath contains $CaNO_3$ 80–100, MnO_2 10–15 and H_3PO_4 3–10 gm/litre and is used at 100° C. The time of treatment is 40–45 min.—A. D. H.

Electrostatic Painting. R. Tinley. (*Sheet Metal Ind.*, 1956, **33**, July, 444–446, 454). An outline of the principles of Ransburg No. 2 Process is given and recent developments are described. These include the reciprocating-disc process and the split-pattern bell-type equipment. The article ends with a description of the equipment required for a complete installation.—A. H. M.

POWDER METALLURGY

Calculation of the Pressure Conditions Occurring During the Compression of Powders. K. Torkar. (*Arch. Eisenhüttenwesen*, 1956, **27**, Apr., 285–288). An equation is evolved on the assumption of elastic strain. The formulæ of Ballhausen, Unckel, and Rankine for the ratio of radial and axial stress were used as a basis for experiments from which the friction coefficient was determined by extrapolation to the case of zero ram pressure.

Study of the Production of a Sintered M-K Magnet. T. Mishima, Y. Mishima, and K. Shida. (*Tokyo Univ. Fac. Eng. Annual Report*, 1954, 83–89). A study of the effect of sintering conditions in a reducing atmosphere of pressed square rods, using Fe–Al alloy instead of pure Al powder, on magnetic properties.

Process of Sintering of M.K. Magnets II. T. Mishima, Y. Mishima, and K. Shida. (*Tokyo Univ. Fac. Eng. Annual Report*, 1955, 78–83). Density, pore size distribution and magnetic properties are related to sintering conditions in the composition 12·5% Co, 18% Ni, 11% Al, 6% Cu in iron. At 1100° shrinkage of pores and densification hardly occur, but diffusion goes on slowly. At 1200° pores shrink rapidly due to liquid flow up 90 min. At 1300–1350° solid phase sintering begins in 30 min and proceeds rapidly. Temperature is more important than time in relation to magnetic properties.

On the Spontaneous Ignition Temperatures of Metal Powder G. Costantinides. (*Pubblicazioni delle Facolta di Scienze e di Ingegneria dell' Universita di Trieste*, Series B, 1953, (128), 383–390). Iron and other powders are investigated. Particle size and concentration of dispersion have effects analogous to similar factors in previous work on organic compounds.

FERRITES, CERMETS, AND CARBIDES

Ferrites. F. Brailsford. (*J. Inst. Elect. Eng.*, 1956, **2,** Sept., 503–505). A brief historical and general account introducing a forthcoming discussion.

High-Resistivity Nickel Ferrites—the Effect of Minor Additions of Manganese or Cobalt. L. G. Van Uitert. (*J. Chem. Phys.*, 1956, **24,** Feb., 306–311). Critical amounts improve resistivity.

Ordering and Antiferromagnetism in Ferrites. P. W. Anderson. (*Phys. Rev.* 1956, **102,** May 15, 1008–1013). The octahedral sites in the spinel structure are shown to form one of the anomalous lattices in which it is possible to achieve essentially perfect short-range order whilst maintaining a finite entropy.—E. E. W.

Heats of Formation of Hexacalcium Dialumino Ferrite and Dicalcium. E. S. Newman and R. Hoffman. (*J. Res. Nat. Bur. Stand.*, 1956, **56,** June, 313–318). The heat of formation of these two compounds from their oxides has been determined as $-18{\cdot}3$ and $-7{\cdot}3$ kcal/mole respectively.—B. G. B.

Magnetic Properties of Rare Earth Ferrites $5Fe_2O_3$, $3M_2O_3$. Experimental Results. R. Pauthenet. (*Compt. Rend.*, 1956, **243,** Nov. 12, 1499–1502).

On the Uni-axial Anisotropy Induced by Magnetic Annealing in Ferrites. S. Taniguchi and M. Yamomoto. (*J. Phys. Soc. Japan*, 1956, **11,** May, 604–605). A modification of the authors' theory is outlined, to account for observations by Bozarth and others of the effect of magnetic annealing in single crystals of cobalt zinc ferrite.—J. G. W.

Study of Titanium Carbide base Cermets. I. M. Sugiyama, Y. Mishima, K. Shida, and S. Ito. (*Tokyo Univ. Fac. Eng. Annual Report*, 1955, 84–90). Compositions of 80% TiC and 20% pure metal or alloy binder were pressed into square bars and sintered *in vacuo*. Microstructures, hardness and transverse strength are shown, also oxidation curves. The binders used were Co, Ni, Fe, 94 Fe–6 Si, 94 Fe–6 Al, 70 Fe–30 Cr, 94 Ni–6 Si, 94 Ni–6 Al, 80 Ni–20 Cr.

Mechanical Properties at Room Temperature of Four Cermets of Tungsten Carbide with Cobalt Binder. A. E. Johnson. (*NACA TN* 3309, 1954, pp. 18; *T.I.D.U. List* 485).

Diffusion of Cobalt, Iron, and Nickel into Titanium Carbide. C. R. Turnbull and W. G. Lawrence. (*PB* 114892, 1952, pp. 7; *T.I.D.U. List* 531). Autoradiographic techniques are described, including a sectioning process.

Cemented Borides (Physical Properties). F. W. Glaser, D. Moskowitz, and M. J. Ford. (*PB.* 117522, 1954, pp. 18; *T.I.D.U. List* 485). An account of Borolite IV, a Cr-Mo boride.

PROPERTIES AND TESTS

Mechanical Testing of Steel. S. Visvanathan. (*Tisco*, 1956, **3,** July, 75–85). The author discusses the objects of mechanical testing and gives a description of the various tests employed in terms of tensile, ductility, hardness, impact, fatigue, and creep testing. The variables that may affect the data obtained are analysed and the effect of size is indicated. Typical mechanical properties of various steels are given as examples. (17 references).—L. E. W.

The Significance of Test Results on Steels in Relation to Performance and to Specifications. E. H. Bucknall. (*Tisco*, 1956, **3,** July, 163–172). The author discusses broadly how test results can be related to expected behaviour. The factors involved in the application of steels are considered and the significance of specifications is dealt with. (16 references).—L. E. W.

Operation of Testing Laboratories under Quality Control and Work Measurement. W. B. Kennon. (*Nondestructive Test.*, 1956, **14,** July-Aug., 22–25). Managerial aspects of several highly diversified laboratories operated as a staff function in maintenance engineering are discussed. Personnel reactions to the introduction of new methods have been studied by the author and some of the observations are noted.

Physics of Metals. *Conservatoire National des Arts et Métiers, Semaine d'étude de la Physique des Métaux. Essais de Laboratoire et Comportement en Service*, 1955, pp. 173). **Introduction,** P. Laurent (3–4). **Experiments on Railway Rolling Stock.** L. Gaspard (5–18). Tests of various kinds on a carriage are reported. **Fatigue of Aircraft Structures.** W. Barrois. (19–39). An investigation showing that knowledge of stresses is insufficient for rigid mathematical analysis so that large factors of safety are needed in vital situations. A partial analysis is presented and fatigue estimated at an average of about 5×10^4 cycles on the Wöhler curve. **Considerations on the Tests Provided for in Specifications.** J. Bernard. (41–50). A discussion of steel specifications is presented with regard to general properties, (cohesion, elasticity and plasticity) and the principal tests usually specified: tensile, bend, etc., followed by a discussion of the meaning and value of such tests and of analyses. General conclusions are drawn as to the generally empirical or ad hoc nature of the tests and the difficulties raised by continuous production. **Definition and Control of Metal Quality.** M. Prot. (51–55). A discussion of French standard specifications with reference to their objects, their value, and the cost of making the required tests. **Dislocations and Plasticity of Solids.** J. Philibert. (57–70). Elastic limit and metal whiskers are discussed followed by the theory of accumulation of dislocations and brittle fracture with electron micrographs of replicas from iron and steel. The movement of dislocations is then treated, and the mechanism of ageing, kinetics of precipitation and effect of inclusions. (Mathematical appendix and 19 references). **Studies of Consolidation Factors and Strain under Uni- and Bi-axial Stresses.** C. Crussard. (71–81). Deformation and glide in polycrystalline systems are discussed in relation to metal texture. Examples are drawn from aluminium alloys. (The remaining papers are reprints from *Métaux–Corrosion–Indust.*)

Computer Control for Steelworks Engineering. (*Brit. Steelmaker*, 1956, **22,** Sept., 264–266). An indication is given of the attractive time and labour saving factors offered by electronic computers in the control of intricate and precise machining of such items as dies and rolls. The principles of the system are described, and the machines and processes are outlined step by step.—G. F.

Effect of Dispersions on Mechanical Properties. J. E. Dorn and C. D. Starr. (*PB* 114678, 1953, pp. 42; *T.I.D.U. List* 531). An outline of the dependence of mechanical properties on the microstructure of polyphase alloys. The correlations, so far, are only qualitative.

Chemical Aspects of the Structure of Defective Solids. A. Cimino. (*Chim. e Ind.*, 1956, **38,** Mar., 189–201). A review of order-disorder theory in ionic crystals, oxides, sulphides, ferrites and other semi-conductors.

On the Fundamentals of the Theory of Elasticity of Physically Non-Linear Non-Homogeneous Bodies. W. Olszak and M. Zyczkowski. (*Bull. Acad. Polonaise Sci.*, 1956, **4,** Class 4, (2), 63–72).

Deformation and Flow of Solids. R. Grammel (editor). (*IUTAM Colloquium, Madrid*, 1955, pp. 324). **Strains in Crystalline Aggregate.** G. I. Taylor. (3–12). Strain equations for Al and polycrystalline Fe are derived. **Effect of Intergranular Boundaries on Cold Drawing in Metals.** B. Jaoul. (13–24). [In French]. Slip is compared in mono- and poly-crystals of Al and Cu. **Dislocations and Lattice Theory.** G. Leibfried. (25–32). [In German]. **Theories of Fracture in Metals.** N. F. Mott. (53–59). Brittle and ductile fractures and fatigue are considered in terms of dislocation theory and crack formation. **Dislocations and Brittle Fracture in Metals.** J. R. Low, Jun. (60–72). Cleavage steps are illustrated and discussed. **The Origin of Dislocations in Crystals Grown from the Melt.** F. C. Frank. (73–78). A mechanism is advanced. **Mechanisms of Fracture in Metals.** C. Crussard, J. Plateau, and Y. Morillon. (117–128). [In French]. Four stages in crack formation are distinguished, though the modes of breakage are various in steels, especially in regard to deformation and the effect of intergranular boundaries. **Foliated Structure of Boundaries in Metals.** F. T. du Cros. (137–146). [In French]. Lattice joints at crystallite boundaries are discussed. **A New Theory of Plasticity.** M. Velasco de Pando. (171–175). [In Spanish]. Mathematical. **Second Order Effects in Infinitesimal Elasticity.** M. Reiner. (203–207). Torsion in steel and copper wires has been shown to produce "infinitesimal" effects of which a mathematical theory is presented. **On Physical Effects in Cavitation Damage.** M. S. Plesset. (218–235). Ultrasonic generation is described and damage to non-ferrous metals and studies with a photoelastic plastic are shown. **Viscosity and Irreversible Deformations.** H. le Boiteux. (264–278). Criteria for ductility and brittleness are derived in discussion of materials in which viscosity is not negligible. **The Process of Damage to Metals by Creep.** I. A. Oding and W. W. Burdukski. (298–303). [In German]. The derivation is compared with tests on three steels. **The**

Effect of Small Viscous Inclusions on the Mechanical Properties of an Elastic Solid. J. G. Oldroyd. (304–313).

Photoelastic Measuring of Elastic and Plastic Deformations and Crystalline Fragmentations in Metals. F. Zandman. (*Rev. Mét.*, 1956, **53**, Aug., 638–644). A new technique is described which enables a complete photoelastic analysis of the actual object whatever the shape, size or material. The specimen is covered by a special photoelastic plastic layer in liquid or sheet form which becomes birefringent by the effect of the deformation. Results obtained using the technique are given and discussed together with illustrations of the type of phenomena observed.—B. G. B.

On a Classification of Non-Homogeneous Elasto-Plastic Bodies. W. Olszak. (*Bull. Acad. Polonaise Sci.*, 1956, **4**, Class 4, (1), 29–35). A mathematical theory of small deformations is given.

Some Simple Experiments on the Dynamic Plastic Behaviour of Mild-Steel Beams. E. W. Parkes. (*Brit. Welding J.*, 1956, **3**, Aug., 362–366). The experimental deformations of a series of mild steel cantilevers and encastré beams struck by moving masses are compared with the deformations predicted by analysis based on the concept of a constant dynamic plastic moment. It is found that at sections remote from the point of impact good agreement is obtained between theory and experiment.—U. E.

Dislocation Theories of Strength and Plasticity. A. V. Stepanov. (*Research*, 1956, **9**, June, 227–236; *Bull. Acad. Sci. U.S.S.R.*, 1954, **18**, 90).

The Stress to Move a Free Dislocation in Alpha Iron. J. Heslop and N. J. Petch. (*Phil. Mag.*, 1956, **1**, 8th Series, Sept., 866–873).

On the Experimental Determination of the Density of Dislocations in Non-Deformed Metallic Crystals. H. Lambot. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Aug., 228–232). Methods available for determining the density of dislocation centres in metallic grains prior to deformation are discussed Recent optical measurements give values of the order of 10^5 to 10^7 dislocation lines per cm², X-ray measurements give densities of the order of 10^5 to 10^6 dislocation lines per cm². The agreement between these two techniques is considered satisfactory.—B. G. B.

Biaxial Plastic Stress-Strain Relations of a Mild Steel for Variable Stress Ratios. J. Marin and L. W. Hu. (*Trans. Amer. Soc. Mech. Eng.*, 1956, **78**, April, 499–509). Further experimental checks on the validity of the simple flow theory of plasticity are reported. Biaxial stresses were produced by subjecting machined cold-drawn seamless mild steel tubular specimens to internal pressure and axial tension. Constant and variable biaxial stress ratios were used; the results did not support the simple flow theory of plasticity. The validity of the distortion-energy criterion was tested and the difference between experimental and theoretical results could not be attributed to experimental error or material anisotropy. The results of a special variable stress ratio test were in poor agreement with simple flow theory and in approximate agreement with the slip theory. Further test results did not agree with the concept of the isotropic expansion of loading functions.—D. H.

The Effect of Static Mean Stress on the Damping Properties of Materials. N. L. Person and B. J. Lazan. (*Amer. Soc. Test. Mat. Preprint No.* 85, 1956). New bending vibration decay equipment is described for determining the effect of static mean stress on the damping of materials. Tests were performed on SAE 1020 steel, aluminium, magnesium, annealed titanium alloys, and glass laminate. The maximum stress on the specimen was kept below the cyclic stress sensitivity limit, where damping is unchanged by stress history.

Remarks on the Subject of the Relationships Existing between the Tensile Strength, Elastic Modulus and Hardness of Low Phosphorus Unalloyed Grey Cast Irons. M. Ferry. (*Fonderie*, 1956, Apr., 143–150). The effects of microstructure on the elastic modulus and hardness of ordinary grey cast irons is discussed and it is concluded that the elastic modulus depends only on the graphite (amount and form), and that the hardness is mainly determined by the structure of the matrix although it is not entirely independent of the nature of the graphite distribution. Experimental data are analysed to confirm the relationship $R_t = K.E.H.$ where R_t is the tensile strength, E the elastic modulus, H the hardness and K a constant. The variation of K with microstructure is discussed and interpreted in terms of the notch effect produced by the graphite. The decreased strength shown by cast iron as compared with a steel having the same matrix structure is attributed to this notch effect and also to the effect of the graphite on the elastic modulus of the cast iron.

Theory of Yield Point and Transition Temperature of Mild Steel. F. Forscher. (*J. Appl. Mech.*, 1956, **23**, June, 219–224). A yield criterion is proposed which accounts for the dependence of yield-point phenomenon of mild steel on strain rate, duration of stress, temperature and stress state. The theory is developed on the basis of a "structural" model by which the behaviours of microscopic and sub-microscopic elements are idealized. The theory postulates as yield criteria, a critical number of relaxation centres (active Frank-Read sources) or a critical size of relaxation centre. The transition temperature phenomenon is considered to be the result of an inhibition of yielding (upper yield point) by means of geometry, temperature and/or strain rate. A relation is given which expresses its dependence on the state of stress and strain rate.—D. H.

Determination of the Yield Point of Steels by Magnetisation. P. Réti. (*Acta Techn.*, 1956, **15**, (3–4), 347–359). [In English]. A small sensitive magnetometer is described. On account of the permeability changes occurring at the yield point, the instrument was successfully used for its determination in low carbon steels, as well as in Cr, Cr–V and Mn steels in which the yield point is difficult to detect by conventional methods.—P. F.

Evaluation of the Strength of Steels. M. Roš and A. Eichinger. (*Rev. Mét.*, 1956, **53**, Oct., 757–766). Tensile tests are generally considered to measure the static strength of steel, but it is considered that the rupture elongation is dependent on several characteristics. They should be replaced by constant stretching and measurement of the change in cross-sectional area, and by measurement of the bending coefficient. Impact tests on notched bars are expressed by resilience numbers. The results of resilience tests carried out under standard conditions can only be correctly assessed in conjunction with the complete results of static and dynamic tests.—B. G. B.

The Ductile Fracture of Polycrystalline α-Iron. N. J. Petch. (*Phil. Mag.*, 1956, Series 8, **1**, Feb., 186–190). Ductile fracture requires a compressive stress on the dislocation arrays close in value to that required for cleavage. A relationship between ductile fracture stress and grain diameter is derived; this is of the same form as that found for cleavage, and the slope constant is practically the same.

The Lowering of Fracture-Stress due to Surface Adsorption. N. J. Petch. (*Phil. Mag.*, 1956, Series 8, **1**, Apr., 331–337). This lowering of fracture-stress is calculated from Gibbs' adsorption isotherm and the Griffith and dislocation theories of fracture. Surface adsorption may cause the embrittlement of iron by hydrogen; this possibility is shown to agree well with measured fracture stresses. (12 references).—K. E. J.

Investigation of Static and Fatigue Resistance of Model Pressure Vessels. J. Dubuc and G. Weller. (*Welding J.*, 1956, **35**, July, 329s–337s). The tests were made on model vessels (ID = 12 in., t = $\frac{3}{4}$ in.) of A-201, Grade A steel and A-302, grade B steel, and static tests were carried out at + 70 and at − 50° F. At both temperatures the A-302 steel vessels showed much higher yield and ultimate strengths than the A-201 steel vessels. Under fatigue loading these model vessels have exhibited a life of more than 500 cycles at stresses near the ultimate strength of respective materials. The heads were found to be a weak zone and the most vulnerable places in the shell were in openings for attachments in the form of nozzles.—U. E.

High-Temperature Vacuum Furnace for Tensile Testing. E. A. Smith and R. W. Guard. (*Rev. Sci. Instruments*, 1956, **27**, June, 386–387). Temperatures up to 1600° C are attained.

Prediction of Drawing Properties from Tensile Tests. E. N. Ludington. (*Metal Progress*, 1956, **70**, Aug., 93–96). The load required to draw cylindrical cups and the maximum reduction possible are shown to be accurately predicted from the ultimate tensile properties of the original sheet.—B. G. B.

Grain Size Affects the Properties of Metals and Alloys. K. Camenisch. (*Pro-Metal*, 1956, **9**, Aug., 698–705). Measurements of grain size, effects on tensile properties and hardness effects of plastic deformation and annealing on grain size, and cold forming effects and choice of materials are discussed.

Lowering the Apparent Limit of Elasticity of Steels after Initial Drawing (at Ordinary Temperature). F. Campus and

K. Gamski. (*Compt. Rend.*, 1955, **241**, Nov., 28, 1552–1554). Results are given of flow tests on a hard and a semi-hard steel. The test-pieces were first stressed up to or over their apparent elastic limits and then immediately given a second pull below this limit of elasticity. If a steel undergoes a slight elongation below its apparent limit of elasticity, the flow may become considerable if the stress is maintained for a long enough period.—G. E. D.

The Lithoidal Fracture of Structural Steel. S. S. Nosyreva and A. M. Polyakova. (*Doklady Acad. Nauk S.S.S.R.*, 1955, **103**, (3), 431–2). Radioactive ^{35}S was used in sulphide inclusions to study the mechanism. Normalized tempered specimens were fractured and examined by autoradiography showing deposition of sulphide at austenite grain boundaries. At higher temperatures the structure was not shown.

Researches on Damping in Annealed or Cold-Worked α-Iron in Presence of Small Additions of Carbon and Nitrogen. W. Köster. (*Publ. Assoc. Ing. Faculté Polytechn. Mons*, 1956. Reprint, pp. 15). A study of carbide precipitation is described and of the effect of ageing on properties, with electron micrographs.

Theories of Fracture. V. G. Paranjpe. (*Tisco*, 1956, **3**, July, 144–152). The theories of common types of fracture are outlined and it is seen that the phenomenon of brittle fracture is the best understood at present while the mechanism and criteria of ductile failure are far from clear. It is stressed that all the theories have to be modified for practical application since structural heterogeneities exert a pronounced effect on both the initiation and propagation of fracture. (32 references).—L. E. W.

Notch Tensile Behaviour of Face Centred Cubic Metals. E. J. Ripling. (*Amer. Soc. Test. Mat. Preprint No.* 80, 1956). The notch insensitivity of face-centred cubic metals (including a stainless steel) when tested at a constant rate and testing temperature was found to be a linear function of the unnotched strain hardening exponent.—B. G. B.

A Test of Theoretical Evaluation in the Study of the Strength of Grey Cast Irons. J. Navarro Alcacer. (*Inst. Hierro Acero*, 1956, **9**, Apr., 425–431. Special Number). [In Spanish]. The coefficients of strength e_a, ξ, and T which have been derived by various authors are shown to be interrelated by the equation $e_a \cdot \xi \cdot T = \chi$; where $e_a = E_a/E_o$, the ratio of the elastic modulus of the steel matrix to that of the cast iron as a whole which is a measure of the quantity and distribution of the graphite; $\xi = f_t/f_e$, the ratio of total to elastic bending which is a measure of the graphite shape; $T = \sigma_f/f_t$ where σ_f is the flexural strength and is a measure of the graphite size; and χ, which is constant depending solely on the conditions of the bend test. This approach gives a clarification of the Meyersberg isoflexural lines and a link with Collaud's equation for tensile strength. The derived equation for tensile strength σ_t is given by $36 \cdot 10^{-6} \Delta \cdot E_o/2\xi$, where Δ = Brinell Hardness is shown to be applicable in the limiting cases of steel and nodular cast iron.—P. S.

The Effects of Strain Rate and Temperature on the Stress-Strain Relations of Deep-Drawing Steel. R. J. MacDonald, R. L. Carlson and W. T. Lankford. (*A.S.T.M. preprint* 1956, No. 73, pp. 17). A range of strain rates at different temperatures was applied to a killed temper-rolled steel. Yield-point phenomena and work-hardening characteristics are affected by variations in rate and temperature. Mechanism is discussed, and an expression advanced for strain hardening. Data are presented graphically.

Effect of Strain Rate on the Behaviour of Iso-Elastic Wire Strain Gauges. A. H. Meitzler. (*Rev. Sci. Instruments*, 1956, **27**, Jan., 56). Anomalous responses are noted.

Strain-Gage Bridge Sensitivity Control. P. K. Stein. (*Product Eng.*, 1956, **27**, Jan., 200–204). In a strain-gauge bridge the sensitivity can be regulated by means of a variable resistance in series with the supply voltage, and a mathematical discussion is given on the design and application of a control system for different gauge factor settings. Reference is also made to the effect of gauge factor setting on the initial zero reading of the bridge. This is the first of two articles on the subject.—E. A. C.

Effects of Neutron Irradiation in Steel. J. C. Wilson and R. G. Berggren. (*Amer. Soc. Test. Mat., Proceedings* 1955, **55**, 689–707). The shape of the stress-strain curve is altered and yield stress of austenitic stainless steels depends on strain rate. In carbon steel the yield point is sometimes eliminated and ductility decreased. Evaluating metals for use in reactors is discussed.

Tension and Torsion Properties of Some Metals under Repeated Dynamic Loading, (Impact). D. B. C. Taylor and A. Z. Tadros. (*Inst. Mechanical Eng.*, 1956, Preprint, pp. 15). Two testing machines are described of the falling-weight type, yield stress being measured electronically and total extension (or twist) being limited. Measurements on steels and aluminium alloys were made. The criterion of failure appeared to migrate away from the Mises-Hencky theory towards the theory of maximum principal stress.

Full Scale Ship Structural Experiments and the Effect of Unfair Plating in Tension. T. H. Evans. (*J. Amer. Soc. Naval Eng.*, 1956, **68**, Feb., 57–78). A discussion mainly of crack initiation and propagation in welded ships, is presented with a wealth of data, largely tabulated.

Bending and Impact Tests of Cast Iron, Cast Steel and Nodular-Iron Valve Bodies. J. O. Jeffrey and R. H. Hanlon. (*Mech. Eng.*, 1956, **78**, Jan. 23–27, 30). Commercial standard 6 in. valve bodies were tested in bending at 900° F and under drop-impact tests at 40° F. Results indicate that ferritic nodular cast iron valves possess sufficient shock resistance and ductility to avoid brittle fracture under these conditions.

The Impact Test in Materials Testing. W. Späth. (*Radex-Rundschau*, 1956, Mar., 39–46). After a discussion of the test with reference to stress resistance theory a new "slow falling pendulum" instrument is described which applies the load at a rate between that of static load and ordinary impact, allows of the simple measurement of maximum load, and eliminates loss due to the kinetic energy of fragments.

Effects of a Number of Heat Treating and Testing Variables on the Notch Strength of 4340 Steel. G. Sachs, V. Weiss and E. P. Klier. (*Amer Soc. Test. Mat. Preprint No.* 71, 1956). Tests on sharply notched bars performed at sufficiently low temperature clearly disclose the tendency of 4340 steel (low alloy steel for aircraft use), to be highly notch-sensitive on static loading, if tempered at temperatures between 500 and 700° F. These tests also reveal that a two-step quenching procedure leads to high-strength steel conditions that are superior to those obtained on conventional oil quenching and tempering.—B. G. B.

Notch and Smooth Bar Stress-Rupture Characteristics of Several Heat-Resistant Alloys in the Temperature Range Between 600 and 1000° F. J. G. Sessler and W. F. Brown Jun. (*Amer. Soc. Test. Mat. Preprint No.* 76, 1956). Smooth and sharply-notched bar stress-rupture tests were carried out on a number of heat-resisting alloys in the temperature range between 600 and 1000° F for rupture times up to 1000 h. Evidence is presented that the moderately elevated temperature rupture strength of modified ferritic steels can be considerably increased by heat treating to higher strength levels. However, a practical strength limitation appears to exist in that there is a progressive development of notch rupture sensitivity as the strength level is increased.—B. G. B.

Effect of Time and Temperature on Impact and Tensile Properties of Hot-rolled Low-carbon Steels during Strain-ageing. F. Garofalo, G. V. Smith and D. C. Marsden. (*Amer. Soc. Test. Mat., Proceedings* 1955, **55**, 708–718). Tests on three commercial steels are reported. Ageing for periods up to 11000 h was carried out.

The Falling Weight Test for Rails. A. S. Babb. (*Rail. Steel Topics*, 1956, **3**, Spring, 19–29). Specifications are reviewed.

Displacement of Energy Levels of Iron Atoms during Cold Deformation. A. I. Krasnikov, L. I. Sotnikova and L. G. Orlov. (*Doklady Akad. Nauk S.S.S.R.*, 1955, **102**, (5), 943–945). The shift of the doublet line Ka_1–a_2 was measured using fluorescence from an exciting beam of X-rays. Changes were greater with chrome and chrome-nickel steels.

Colloquium on Fatigue. (*International Union of Theoretical and Applied Mechanics, Stockholm, May* 25–27, 1955. *Proceedings*). **Critical Study of the Concept of Damage Applied to an Extended Series of Fatigue Tests.** F. Bastenaire. (1–13). [In French]. Equations are given and their applications illustrated, the derivations are not always shown in full. Descriptions of damage by a single parameter and by two or more are considered. **Statistical Studies on Fatigue by the Method of Progressive Loading.** F. Bastenaire, R. Cazaud and M. Weisz. (14–23). [In French]. Tests on a semihard steel are described with reference to the Wöhler curve, the fatigue limit at constant load, and tests with progressive

loading, and all are treated statistically and compared. **Contribution to the Study of Fatigue with Progressive Loading Tests.** A. Ferro and U. Rossetti. (24–34). [In French]. Steel and duralumin are studied on a Prot machine and the curves shown and the fatigue limit computed. **Theories Relating to Fatigue of Materials under Combinations of Stress.** W. N. Findley. (35–42). A review of earlier work on mode of fracture, effect of static stress, effect of compression, effect of static torsion on alternating bending and effect of static bending on alternating torsion, modified theories, effect of anisotropy, and explanation for variations in bending/torsion ratio. **Effect of Simultaneous Cyclic Variation of Stress and Temperature on a High Temperature Material.** A. Fransson. (43–52). A method of testing with special reference to gas turbine blades is described. Oxidation and diffusion of nickel is shown to occur. **Physical and Statistical Aspects of Cumulative Damage.** A. M. Freudenthal. (53–62). A mathematical approach to the prediction of fatigue life. **Fatigue Strength by Statistical Changes of Strain Amplitudes.** E. Gassner. (63–65). [In German]. **New Statistical Methods Applied to the Analysis of Fatigue Data.** F. Gatto. (66–77). **On Deformation Phenomena in Steels under Alternating Loads.** M. Hempel. (78–91). [In German]. Changes in crystal orientation and crack formation are discussed and illustrated. Slip planes are described in relation to cracking. Replica and phase-contrast methods are shown. (With discussion). **The Effect of High Loads on Fatigue.** R. B. Heywood. (92–102). Occasional overloading (of Al alloys for aircraft construction) is shown to improve fatigue life. **Modifications of Crystalline Texture Produced by Alternating Stresses.** R. Jacquesson. (103–111). [In French]. Work on aluminium and on steel is described with a mathematical treatment. **Fatigue of Steels at Constant Strain Amplitude and Elevated Temperature.** A. Johansson. (112–122). Test apparatus is described and the results obtained on 5 alloy steels at 20°, 300°, and 500°, using four strain levels at each temperature. Metallographic observations are reported. **A Theoretical Definition of Fatigue Limit.** A. Kammerer. (123–130). [In French]. **Effect of Geometric Size on Notch Fatigue.** P. Kuhn. (131–140). A method of estimation is developed for steels and Al alloys. Calculated and experimental curves are shown for rotating beam specimens. **Recent Work at the Sarrebruck Metallurgical Research Institute on Fatigue.** P. Laurent. (141–147). [In French]. Statistical method, effect of surface condition, effect of grain size on fatigue limit in Armco iron and use of magnetic measurements are discussed. **Some Experiments on the Processes in the Surface Layers in Fatigue Testing.** O. Lissner 148–159). [In German]. Schaub's hypothesis is mentioned and the planning and results of a series of tests on four steels are discussed and tabulated. The surface layers were removed during the tests, producing increased fatigue life. **Fatigue Tests by Bending at Superposed Frequencies.** L. Locati. (160–168). [In French]. Apparatus is described producing superposition of two very different frequencies instead of the usual amplitude modulation type. Steel and duralumin were studied and the results tabulated. Within limits the effect of the higher frequency was small. **The Object of Fatigue Testing in Switzerland, Illustrated by Experiments on Endurance of Screw Joints.** L. Martinaglia. (169–170). [In German]. **Variability in Fatigue Testing: Sources and Effect on Notch Sensitivity.** F. A. McClintock. (171–177). A discussion of the causes of scatter with a relation between this and local strength variations and a statistical method of deriving notch insensitivity. **On the Mechanism of Breakdown of Metals by Cyclic Loading.** I. A. Oding. (178–185). [In German]. A theory of cavity formation by accumulation of vacancies. **Torsion and Tension Relations for Slip and Fatigue.** R. E. Peterson. (186–196). Slip is related to grain size with random orientation, and fatigue to slip. **Some Peculiarities of Contact Fatigue.** A. I. Petrussewitsch. (197–209). [In German]. Surface conditions of steels are related to fatigue properties in rolling. **Some Observations on the Propagation of Fatigue Cracks.** C. E. Phillips. (210–217). Work at the Mechanical Engineering Research Laboratory is reported. Mild steel bars with V-notches were used and the size of non-propagating cracks measured. Copper, nickel-chromium steel and aluminium alloys were also used. **Some Investigations of Cumulative Damage.** F. J. Plantema. (218–228). Aluminium alloy for aircraft use was investigated. **A Guide to Statistical Methods for Use in Fatigue Testing.** J. T. Ransom. (229–234). Four methods from a forthcoming manual are briefly described. **Mechanical Hysteresis in Steels Shown by Large Tension and Compression Fatigue Tests.** J. Salokangas. (235–243). [In German]. A resonance oscillator and the method of tracing the hysteresis curve are described. The form of the (closed) curve is discussed and treated mathematically. **The Mechanism of Fatigue Fracture of Metals.** C. Schaub and W. Liedtke. (244–250). [In German]. A review of previous hypotheses and an account of a theory of the authors' on the basis of the Russell effect involving activated surface areas. **A Proposed Mechanism of Fatigue Failure.** F. R. Shanley. (251–259). An explanation is advanced based on slip at the atomic level. It requires reversal of slip on the same planes. **Recent Researches on Fatigue at the Mechanical Engineering Research Laboratory, East Kilbride.** D. G. Sopwith. (260–268). Effects of size, tests on screw threads, and other topics are mentioned. **Experimental Design and Methods of Analysis used in Studying Effects of Metallurgical Variation on Fatigue.** R. J. Taylor. (269–277). Work at BISRA is outlined. **A Contribution to the Theory of the Fatigue of Metals.** G. V. Uzhik. (278–288). Three questions are posed and solutions discussed. Under what conditions does initial plastic deformation develop? What happens in the zone of concentrated stress after formation of plastic strain and how are the stresses distributed? Does any further redistribution take place under the action of repeated deformation? **Basic Aspects of Fatigue.** W. Weibull. (289–298). Initiation and propagation are considered separately. A damage factor is defined proportional to the number of stress cycles and curves relating crack length to cycles at constant stress amplitude and constant load amplitude are shown. **Precipitation Processes in Steel under Steady and Increasing Stresses.** F. Wever. (299–312). [In German]. Carbide separation in alloy steels is shown, with the effects of fatigue testing. **Bending Fatigue of Large Welded Test Pieces with Regard to Velocity of Crack Propagation.** P. E. Weine. (313–320). The object of the work was to decide on the justification of annealing frames and bedplates of Diesel engines after welding. Specimens were aged for two months after welding and submitted to a one-sided bending stress with an Amsler pulsator. Curves are drawn from Weibull's formula. **Cumulative Damage in Fatigue.** E. W. C. Wilkins. (321–332). Work on aircraft alloys is described. The Palmgren-Miner hypothesis is not assumed in interpretation.

Researches on Fatigue of Metals at Mechanical Engineering Research Laboratory, East Kilbride. C. E. Phillips. (*Trans. Inst. Eng. Ship. Scotland*, 1955–56, **99**, 173–206). Work on pin joints, screw threads, effect of specimen size and fatigue crack propagation is reviewed. The work is discussed and unsolved problems are indicated.

Use of Statistical Methods on Some Problems of Strength Under Repeated Loading. H. Bühler and W. Schreiber. (*Arch. Eisenhüttenwesen*, 1956, **27**, Mar., 201–209). Causes of scatter in the results of fatigue tests are reviewed. Results of tests on aluminium alloys, steel and cast iron are evaluated by statistical methods. Among matters discussed are: the distribution of the number of load cycles to fracture, the estimation of scatter by calculation of the mean relative standard deviation of the logarithms of the numbers of load cycles to fracture, and the dependence of such scatter on various factors including the content of non-metallic inclusions, the diameter of the specimen, surface condition, method of manufacture, notch effect and hardness.

Effect of Alloy Content on the Metallographic Changes Accompanying Fatigue. M. S. Hunter and W. G. Fricke, Jun. (*Amer. Soc. Test. Mat. Proceedings* 1955, **55**, 942–953). Work on Al–Mg alloys is described.

Full Scale Fatigue Tests of Diesel Engine Elements. P. E. Wiene. (*Institute of Marine Engineers, Transactions*, 1956, **68**, Mar., 39–46, discussion 47–59). An account of Danish work on shot-peened springs, on crank throws and piston rods as improved by changes in design, material, machining and and tightening, and on tests on a large welded construction as welded and after annealing. Nitriding and push-pull tests are amplified in the discussion.

On Fatigue Tests under Progressive Stress. N. Enomoto. (*Amer. Soc. Test. Mat., Proceedings* 1955, **55**, 903–917). Mild steel, duralumin and brass were tested at various stress increment rates. Straight lines were obtained from the plot of stress at failure against one-fourth power rate of increment extrapolating to near fatigue limits by conventional methods.

A hypothesis of mechanism is advanced and the method is suggested as a rapid method for endurance limit determination.

Fatigue Properties of Comparable Cast and Wrought Steels. E. B. Evans, L. J. Ebert and C. W. Briggs. (*Amer. Soc. Test. Mat. Preprint, No.* 64, 1956). The relative fatigue properties of comparable cast and wrought steels in the 0·30 to 0·40% carbon range has been studied. The effect of steel composition and heat-treatment, surface finish, direction of stress and section size have been measured.—R. G. B.

Testing Steels for Sensitivity to Brittle Fracture by means of a Bending Fatigue Test. E. Rubo. (*Z. Vd. I*, 1956, **98,** June 11, 913–919). Following a critical appraisal of conventional tests of notch sensitivity, the author shows by reference to data and illustrations that notch sensitivity can be assessed from notched specimens fractured in bending fatigue, namely from the relative area of the surface fractured in fatigue and from its structure. In an investigation of three carbon steels and one manganese steel, the fatigue test ranked the steels differently from the impact test.—J. G. W.

The Behaviour of Long Helical Springs under Fluctuating Load. C. L. Stangaitis and H. C. Burnett. (*Amer. Soc. Test. Mat. Proceedings*, 1955, **55,** 918–923). Apparatus is described in which the wear due to the guide rod interfered, though lubrication increased the life considerably.

Effect of Annealing (650° C) on Bending Fatigue of Large Welded Test Pieces. P. E. Wiene. (*Welding J.*, 1956, **35,** May, 261s–264s). The effect of annealing welded steel plate of 0·12–0·18% C, 0·14–0·25% Si, 0·50–0·77% Mn composition (low hydrogen electrode) at 650° C was investigated and it was found that the bending fatigue strength increased by 20%.

Effect of Structure, Notches and Shape of Test Bars on Pulsating Fatigue Strength of Arc Welded Butt Joints. K. Wellinger and P. Gimmel. (*Schweissen u. Schneiden*, 1956, **8,** Feb., 53–61). The effect of structure, notches and shape of test piece on pulsating fatigue strength was investigated. It was found that the structural constitution has no great effect on the weld quality. The presence of notches decreases fatigue strength depending on their shape and size. The harder material did not fail when exposed to a higher prestress treatment compared with a softer steel.—U. E.

Creep and Design. W. F. Simmons. (*Batelle Tech. Rev.*, 1956, **5,** July, 10–14). A review of the phenomenon and allowances necessary in turbines and aircraft equipment is given.

The Process of Fracture of Metals during Creep. I. A. Oding and V. S. Ivanova. (*Doklady Akad. Nauk, SSSR*, 1955, **103,** (1), 77–80). A discussion of the Greenwood theory of the influence of voids. It is concluded that failure is due to the accumulation of voids, possibly near existing porosity, production of cracks, and growth of these by further pore migrations.

Effect of Strain-Rate History on the Creep Behaviour of an Alloy Steel at 800° F. H. A. Lequear and J. D. Lubahn. (*Amer. Soc. Test. Mat., Proceedings*, 1955, **55,** 719–723). Cr–Mo–V steels were used. Quickly strained specimens had 30 times the creep rate of slowly strained specimens at common stress. Interrupted creep tests failed to disclose any strain-ageing effects to explain the rate history effect.

An Empirical Relationship Between Rupture Life and Minimum Creep Rate in Creep-Rupture Tests. F. C. Monkman and N. J. Grant. (*Amer. Soc. Test. Mat., Preprint, No.* 72, 1956). An empirical relationship has been found to exist between rupture life and minimum (secondary) creep rate for a large number of alloys. This relationship should enable one to estimate the rupture life once the minimum creep rate has been determined for a particular creep-rupture test. The effects of such variables as testing stress, temperature, composition, and total ductility were investigated for their effects on the empirical relationship.—B. G. B.

Compression-Creep Properties of Several Metallic and Cermet Materials at High Temperatures. L. A. Yerkovich and G. J. Guarnieri. (*Amer. Soc. Test. Mat. Proceedings*, 1955, **55,** 732–756). Apparatus is described and tests recorded on molybdenum, heat-resisting alloys and cermets at 1350–1800° F. Some comparisons with tension tests were made.

Fractures in Service. E. K. N. Nambiar. (*Tisco*, 1956, **3,** July, 153–162). The author discusses, and gives practical examples of, fractures due to simple overload and to fatigue. The sources of stress-raisers are considered and the effects of temperature and corrosion on fracture are dealt with. A number of photographs and photomicrographs of fractured components are included. (12 references).—L. E. W.

Hardness Testing. V. E. Lysaght. (*Steel*, 1956, **139,** June 25, 98–102; July 2, 72–73). Basic methods are illustrated in Part 1, where various testing machines are described and their usefulness indicated. In Part 2, microhardness methods for thin sheets or small areas are considered.—D. L. C. P.

The Physical Meaning of Indentation and Scratch Hardness. D. Tabor. (*Brit. J. Appl. Phys.*, 1956, **7,** May, 159–166). This survey demonstrates that the indentation hardness and scratch hardness measurements of metals and of minerals are essentially a measure of their plastic yield properties.—E. E. W.

Hardness of Tempered Martensite in Carbon and Low Alloy Steels. R. A. Grange and R. W. Baughman. (*Trans. Amer. Soc. Metals*, 1956, **48,** 165–197). The effect of carbon and alloying elements is shown by comparing the hardness of martensite in steels after tempering at various combinations of temperatures and time. An empirical method is described which gives the approximate hardness of tempered martensite to be expected in steels of known chemical composition.

The Hardness of Unalloyed Cast Steel after Water Quenching. (*Fonderie*, 1956, Feb., 75–76). The quenching of plain carbon steel castings is briefly discussed with particular reference to the hardness obtained under various conditions. German and British specifications relating composition and minimum hardness are summarized.—B. C. W.

Formation and Age-Hardening of Iron–Cobalt–Zinc Alloys. W. Köster and H. Schmid. (*Arch. Eisenhüttenwesen*, 1956, **27,** Mar., 211–217). Microscopical and magnetic investigations of the ternary system iron–cobalt–zinc are described. The authors discuss the determination of liquid equilibrium and transformations, the designation of phase spaces in the solid state, and investigations of age-hardening by measurement of hardness and coercivity.

Effects of Plastic Deformation of Austenitic Structural Alloy Steels on Temper Brittleness. L. V. Smirnov, E. N. Sokolkov and V. D. Sadovskii. (*Doklady Akad. Nauk SSSR.*, 1955, **103,** (4), 609–610). Steel was rolled in the austenitic state and immediately quenched to suppress recrystallization. Even 10–20 sec delay altered the results. Impact strength was determined. It is assumed that phase separation changes are responsible for the development of brittleness.

The Brittle Fracture Problem, 1943–1956. C. F. Tipper. (*Brit. Welding J.*, 1956, **3,** Oct., 435–439). A brief historical survey of the brittle fracture problem is presented showing how the importance of the steel was recognized. The direction in which the investigations have proceeded are discussed and reference is made to some of the most controversial aspects still requiring solution.—U. E.

The Brittle Fracture Strengths of Welded Steel Plates. A. A. Wells. (*Inst. Naval Architects*, 1956, Paper No. 6, Mar. 22). An account is given of a series of tensile tests on wide mild steel plates of 1 in. thickness where the plates contained central, notched butt welds parallel to the direction of pull. At temperatures above 4° C the plates sustained yield point average static tensile stresses before brittle fractures occurred. Below 4° C brittle fractures across the weld residual stress zones started from the notches, either spontaneously after welding or with small external loads. With continued loading, complete fractures were obtained only after general yield of the remaining plate cross-sections. At 4° C a single stage fracture was produced at half yield point stress. In further tests between ± 15° C no residual stress zone fractures could be produced at less than yield point stresses in welded plates previously stress relieved by stretching at 40° C. Evidence is presented to show that the behaviour in these tests may be explained mainly in terms of the mechanical effects of weld shrinkage and residual stresses, and metallurgical damage over the narrow weld-hardened zone. (20 references).—L. E. W.

Some Considerations of Wear in Marine Gearing. W. H. Darlington. (*Institute of Marine Engineers, Transactions*, 1956, **68,** Sept., 289–308). Three sets of marine double reduction gears are considered. A transient effect encountered with two of them is discussed, with regard to lubrication, surface stress, vibration and profile. Effects of shaving are considered.

Use of Radio-Active Tracers for Investigating Cutting Tool Wear. (*Machinery*, 1956, **88,** April 20, 511–512). A laboratory has been established at the Hammersmith premises of Alexander Duckham & Co. Ltd., with the primary object of studying the effects of tool life. Measurements of the radio-

active impulses emitted from the swarf indicate the wear of an activated tungsten carbide tool.—M. A. K.

Combating Cylinder Wear and Fouling in Large Low-speed Diesel Engines. M. J. van der Zijden and A. A. Kelly. (*Institute of Marine Engineers, Transactions*, 1956, **68,** Aug., 272–286). An emulsified lubricant has been developed to resist the excessive wear often observed in marine engines running on heavy fuel oil even when the fuel is carefully cleaned. With discussion and authors' reply.

Magnetic Properties of Steels. R. V. Tamhankar. (*Tisco*, 1956, **3,** July, 95–103). After introducing the principles of magnetization and the significance of the various terms, the author discusses in some detail the magnetic properties of steels. The soft magnetic or electrical steels having low watt losses, are mostly iron–silicon alloys and can be produced either by hot- or cold-rolling, the latter having superior properties. The hard magnetic materials, characterized by high Br.Hc products, are either carbon and alloy steels in the hardened state or dispersion-hardening alloys. Non-magnetic steels are used in some special cases where physical strength together with the absence of ferromagnetism is required. The phenomenon of magnetism can be used in studying structural changes and in detecting flaws non-destructively. (14 references).—L. E. W.

Yokes for the Determination of the Magnetic Characteristics of Electrical Laminations. W. Krug. (*Arch. Eisenhüttenwesen*, 1956, **27,** Mar., 193–200). The fundamentals and characteristics of measuring apparatus for the inspection of electrical laminations are discussed, and three types of equipment are compared. Tests on German and American standard laminations are described.

Magnetic Powder Testing as a Steelworks Inspection Method for Rolled and Forged Products. K. E. Johansson. (*Jernkontorets Ann.*, 1956, **140,** (4), 227–264). [In Swedish]. A comparison is made between magnetic and other crack detection methods and details are given of attempts to evalue a rapid and reliable method suitable for the routine inspection of products. New equipment based on impulse magnetization was developed which, based on pulsating d.c., gives constant remanence from sample to sample. Examples are given of equipment for inspecting rods, tubes, and billets.—G. G. K.

Magnetic Particle and Penetration Inspection. R. Bentley. (*Brit. Welding J.*, 1956, **3,** Oct., 494–496). The author describes the principles of magnetic particle and penetration methods of testing which have made rapid progress in recent years.—U. E.

Use of Tap Water in Magnetic Particle Inspection. J. L. McCabe and B. Hirst. (*Metal Progress*, 1956, **70,** July, 77–79). The successful use of tap water containing rust-inhibitors and wetting and antifoaming agents in place of the conventional petroleum distillate as a medium in magnetic particle crack detection is described.—B. G. B.

Magnetization of a Magnetic Single Crystal Near the Curie Point. D. O. Smith. (*Phys. Rev.*, 1956, **102,** May 15, 959–963). The isothermal M–H curves of magnetite in the principal crystallographic directions, measured from room temperature to the Curie Point, show that the anisotropy energy and spontaneous magnetization are a function of temperature.

Rapid Method for Testing the Coercive Force of Electrotechnical Sheet Iron. R. I. Yanus, L. A. Fridman and V. I. Drozhzhina. (*Zavodskaya Laboratoriya*, 1955, **21,** (10), 1193–1197). [In Russian]. A non-destructive method is described in which the tendency of transformer, dynamo and electric motor sheet iron to produce electromagnetic losses is found indirectly by measuring the coercive force. This is done in a special device in which the value of the coercive force is approximately indicated by the strength of a demagnetizing current. The design and theory of the apparatus are considered and results obtained for a transformer and a dynamo iron are presented. The possibilities of the technique for automation are discussed.—S. K.

Ultrasonic Non-Destructive Control of Metals. M. Palmé. (*Corrosion et Anticorrosion*, 1956, **4,** June, 195–210). The principles and practice of the transmission, resonance and echo methods are outlined and control by transverse and superficial waves is described. Examples are given, with emphasis on the testing of items connected with railways.

Non-Destructive Flaw-Detecting: The Use of Supersonics. A. E. Williams. (*Iron Steel*, 1956, **29,** Sept., 439–442). The principle of the ultrasonic method of flaw detecting is outlined and details are given of the method of wiring a typical instrument. Some applications of the method are discussed, including the measurement of wall thickness in tubes and tanks.

Experiments on the Propagation of Short Sound Impulses in Ultrasonic Testing of Materials. E. Kloth. (*Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein-Westfalen*, 1956, No. 216. pp. 79). Mainly mathematical without special reference to metals. Shape, particle size and similar factors are considered.

Mechanical Hysteresis of Metals at High Temperatures. C. Boulanger and C. Crussard. (*Métaux-Corrosion-Indust.*, 1956, **31,** May, 203–213). The application of dislocation theories to explain the properties of metals at elevated temperatures is discussed. The measurement of the oscillation of metal samples under torsion at temperatures up to 1600° C is described and results obtained are considered. Mechanical hysteresis and internal friction are of great importance in determining the properties of metals at high temperatures. The creep of metals is caused by movement of dislocations and the diffusion of dislocations is discussed.—B. G. B.

X-Ray Diffraction Measurement of Phase Composition: Subcommittee XI on Plain Carbon Steel Tempered Martensite Series. W. L. Grube and D. P. Koistinen. (*Amer. Soc. Test. Mat., Proceedings*, 1955, **55,** 626–627). Retained austenite measurements are given.

The Sensitivity, Reproducibility, and Accuracy of X-Ray Diffraction Measurements of Retained Austenite. K. E. Beu. (*Amer. Soc. Test. Mat. Proceedings*, 1955, **55,** 630–643). Carbon and low-alloy steels were examined and iron and chromium $K\alpha$ radiation used, the former being superior.

Determination of Particle Sizes and Lattice Distortion from X-Ray Interferences. V. Hauk and C. Hummel. (*Z. Metallkunde*, 1956, **47,** Apr., 254–260). The influence of cold deformation on the particle size and lattice distortion of ferrite crystals in iron and steel was measured by means of a Philips Goniometer-counter instrument. The results obtained by measuring X-ray line breadths differed considerably from those derived from the first Fourier coefficient of intensity distribution according to Warren and Averbach. The differences can be attributed to inaccuracies in intensity measurements. A comparison was made of particle sizes obtained by the microbeam method and by measuring the width of X-ray lines. (36 references).—L. D. H.

A Versatile X-Ray Diffractometer for Single-Crystal and Powder Studies. A. R. Lang. (*J. Sci. Instruments*, 1956, **33,** Apr., 138–141). A robust instrument is described which is designed as a general purpose diffraction instrument for use in an X-ray diffraction laboratory engaged in a variety of studies.—L. D. H.

An Attachment for High-Temperature Single-Crystal X-Ray Work. L. S. Dent and H. F. W. Taylor. (*J. Sci. Instruments*, 1956, **33,** Mar., 89–91). This attachment, in which a cylindrical nickel foil heating element is used, is suitable for use in taking single-crystal or powder photographs with copper radiation up to 900° C.—L. D. H.

The Screening Effect of Heavy Metals against Gamma-Rays. K. Sedlatschek. (*Planseeberichte*, 1956, **4,** Aug., 37–42). The curve for iron is given.

Specific Heat and Resistivity of Mild Steel. P. R. Pallister. (*J. Iron Steel Inst.*, 1957, **185,** April, 474–482). [This issue].

Thermal Conductivity of Building Materials: Methods of Determination and Results. A. W. Pratt. (*J. Inst. Heating Ventilating Eng.*, 1956, **24,** Aug., 201–226). An account is given of the two methods in use at the Building Research Station, D.S.I.R. One is the usual guarded hot-plate arrangement for steady flow and the other is a transient flow method which also evaluates thermal diffusivity. The latter method may be more suitable for measurements on damp materials. A number of tables of results and diagrams are included. (15 references).—L. E. W.

A New Dilatometer and its Use in Metallography. O. Werner. (*Z. Metallkunde*, 1956, **47,** Jan., 28–36). A short survey of dilatometer development is followed by a description of the construction of an all-electronic recording instrument. Linear variations are recorded in relation to time or temperature with a 250 to 84,000-fold magnification, being transformed into current through an inductive amplifier pickup and Wheatstone bridge. Current and thermocouple voltage are fed to a Leeds and Northrup x-y-co-ordinate recorder. Some applications to ferrous metallography are given. (35 references).—L. D. H.

Total Thermal Contractions of Some Technical Metals to 4·2° K. J. J. M. Beenakker and C. A. Swenson. (*Rev. Sci. Instruments*, 1955, **26**, Dec., 1204–1205). Cast iron and steels were measured.

Simultaneous Measurements of Density, Viscosity, and Electrical Conductivity of Melts. J. D. Mackenzie. (*Rev. Sci. Instruments*, 1956, **27**, May, 297–299). Apparatus is shown working up 1000° with indications of extension to 1800° C.

Fluidity Testing Developments. V. Kondic. (*Found. Trade J.*, 1956, **100**, Jan. 12, 31–36). The metallurgical and foundry aspects of fluidity testing are reviewed and it is concluded that the spiral test is not a satisfactory foundry control test. A star type of test piece with arms of different thicknesses is described and some results obtained with this test are summarized. In conclusion an assessment is made of the fluidity test as a foundry control test.—B. C. W.

Development of a Calorimeter for Temperatures up to 1100° C, and Determination of Reaction Enthalpy of Spinel $FeO.Al_2O_3$ Between 800° C and 900° C. W. A. Fischer and G. Lorenz. (*Arch. Eisenhüttenwesen*, 1956, **27**, June, 375–379). The development of an experimental method for the measurement of small quantities of heat is described, with details of the electrical calibration, the estimated liability to error, and the determination of the enthalpy of formation of the solid reaction $FeO + Al_2O_3 \rightarrow FeO.Al_2O_3$.

Effect of Specimen Dimensions on High-Temperature Mechanical Properties. P. Shahinian and J. R. Lane. (*Amer. Soc. Test. Mat., Proceedings*, 1955, **55**, 724–731). Effects of the ratio of length to diameter in S-816 and monel alloys are reported.

Heat- and Corrosion-resisting Sintered Materials. (2 *Plansee Seminar "de Re Metallica"* 1955). **The Mechanism of Scaling of Metals and Alloys at High Temperatures.** O. Kubaschewski. (18–27). A review with 30 references. **Diffusion in Some Oxide Systems.** J. A. Hedvall. (1–7). Diffusion of iron in ferrites is included. **High-temperature Materials and Methods of Evaluation.** W. B. Crandall and J. R. Tinklepaugh. (344–360). The first section discusses thermal shock. **Microplasticity of Hard Materials.** A. G. Smekal. (28–40). Scratches and indentations are examined by interference methods.

Low Temperature Properties of Steels. S. N. Anant Narayan. (*Tisco*, 1956, **3**, July, 86–94). The author outlines the necessity for a thorough knowledge of the mechanical properties of steels at low temperatures and lists some of the refrigeration processes (and their service temperatures) in which steel parts would be desirable. Changes in tensile properties with decreasing temperature and the notch sensitivity of ferritic steels are discussed. Brittle fracture is dealt with and the effects of variables such as chemical composition, structure, and steelmaking and rolling processes are described. While tensile strength is little affected, there occurs a sudden drop in impact resistance at a transition temperature below which the steel can be of little use. This tendency for brittle fracture is accentuated by the presence of stress-raisers and triaxiality in the stress system. The inherent toughness of the steel is influenced principally by carbon and manganese as also by the presence of impurities and alloying elements. The structure and methods of deoxidation and rolling have a minor effect. The author concludes with a brief consideration of how to choose a steel for low-temperature service. (39 references).

Calculation of Diffusion under Varying Temperature Conditions. B. Ilschner. (*Arch. Eisenhüttenwesen*, 1956, **27**, May, 337–342). The author deals with the solution of the diffusion equation for varying temperature, and solutions for assumed temperature variations (such as cooling in accordance with Newton's Law). He discusses his methods and applies them to a series of examples taken from conventional heat-treatment practice.

The Diffusion of Boron, Carbon and Nitrogen into Transition Metals of the IV, V, and VI Groups of the Periodic System. G. V. Samsonov and V. P. Latysheva. (*Doklady Akad. Nauk, SSSR*, 1956, **109**, (3), 582–585).

METALLOGRAPHY

The Time Laws of Eutectoidal Transformations. B. Ilschner. (*Arch. Eisenhüttenwesen*, 1956, **27**, Apr., 275–280). Observational data are given and the conditions for lamellar arrangement and nucleus formation are enumerated. The fundamentals of undisturbed and restricted growth are discussed, and the time law is derived. Theoretical and observational results are compared.

Zoned Melting with a Temperature Gradient. (*Tek. Tidskr.*, 1956, **86**, June 19, 591–592). [In Swedish]. Used in the production of small quantities of extremely pure metals, this method is based on a fusion zone which is led slowly through a rod of the impure metal. Details are given of theory, length, and travel rate of the fusion zone, composition of the re-solidified zone and applications of the process in the production of single crystals, semiconductors, etc.

High Temperature Furnaces. E. S. White. (*Iron Steel*, 1956, **29**, Apr., 147–149). The author discusses some of the difficulties of making laboratory tube furnaces for working at temperatures up to 1850° C. The construction of a molybdenum-wound furnace, using an impervious recrystallized alumina work-tube and a separate winding tube, is described.

Metallurgical Activities at CARDE. H. P. Tardif. (*Canad. Min. Met. Bull.*, 1956, **49**, May, 372–376). The work of the Canadian Armament Research and Development Establishment is described. The work discussed includes high-strength steels, craze cracking in gun tubes, properties of armour, and photomicrographic study of fractures.

New Auxiliary Equipment for Metallographic Work and Demonstrations. R. Mitsche. (*Z. Metallkunde*, 1956, **47**, Mar., 171–175). Apparatus and equipment is described which serve to simplify metallographic work, or widen the scope of instruments in use. These include a binocular eyepiece with an indicator, a micrometer eyepiece for determinating grain size, a magnetic microscope stage, a demonstration microscope and a heating and cooling attachment.

The β-Ray Microscope and its Uses in Metallography. D. J. Shapland, N. Feather, and A. F. Brown. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Oct., 446–453). A lens system is described by which charged particles emitted from radioactive bodies can be focused. By its means, resolutions of the order of 1μ can be obtained in autoradiography of metal surfaces. The possibilities and limitations of the method are discussed.—B. G. B.

Methods of Electron Metallography. R. Castaing. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Oct., 454–465). The evolution of the replica technique is described. The author has improved the technique developed by R. Heidenreich in which the specimen is thinned until it is transparent to electrons. This covers the range between the optical microscope and the diffraction and low angle scattering of X-rays.

Electron Metallography of Pure Iron and Mild Steel. F. van Wijk. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Oct., 555–558). The structure of pure iron and ferrite in mild steel after electrolytic polishing has been studied. The structures observed are related to the dislocation theory. The study of the deformation of ferrite is considered to be possible on specimens deformed after etching.—B. G. B.

Electron Metallography of Ferrous Materials. J. Nutting. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Oct., 512–526). The great advances in ferrous metallurgy brought about by developments in optical and electron microscopic techniques are summarized. The elucidation of the structural changes occurring during the isothermal transformation of austenite, the ageing of ferrites and tempering of plain carbon martensites are described. Refinements in replica technique and the possibility of changing an electron microscope into a diffraction unit enable the study of the secondary hardening of alloy steels containing strong carbide forming elements. (51 references).—B. G. B.

Direct Observation of Surfaces with the Electron Microscope. The Reflection Electron Microscope. C. Fert. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Oct., 409–414). The image observed by electron reflection microscopy is formed by diffuse electrons. Inelastic scattering predominates and achromatic aberration is the principal cause which limits the quality of the images. The author has modified the von Borries technique and has achieved a resolution of the order of 300Å and straightforward interpretation of the image. Photomicrography of iron and steel surfaces are reproduced.

Summary of the Work of ASTM Subcommittee on Electron Microstructure of Steel. W. L. Grube. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Oct., 526–536). The correct utilization of replica techniques, metallographic polishing and etching is discussed. It has been found possible to differentiate between lower and upper bainite in eutectoid steel, the anneal-

ing of martensite structures has also given information on the evolution of carbide and cementite precipitation.—B. G. B.

A Recent Experimental Method of Solution Etching in Conjunction with Electron Microscopy. H. Goossens. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Oct., 471–476). A method of carbide isolation from the matrix is described which permits the conservation of their relative positions. The results of the application of the technique to the study of carbide precipitation during the isothermal decomposition of austenite and martensite are described.—B. G. B.

Etchants for Temper Brittleness. F. Muñoz del Corral and J. M. Bermudez de Castro y Mosquera. (*Inst. Hierro Acero*, 1956, **9**, Apr., 478–484. Special Number). [In Spanish]. A series of micro-sections of a nickel–chromium–molybdenum steel in the sensitized and tough conditions were etched in a series of 5 etching reagents with a view to correlating microstructure with temper brittleness. The best correlation is obtained with Zephirol-picral which develops clear grain boundaries when the steel is embrittled, and alkaline potassium permanganate which develops grain boundary strings of white spots (dark field illumination). Aqueous picric acid did not give good results.—P. S.

The Potentiostat as a Metallographic Tool. C. Edeleanu. (*J. Iron Steel Inst.*, 1957, **185**, April, 482–488). [This issue].

Observations on the Formation of Graphite in Sub-Eutectic Cast Iron. A. Wittmoser and E. Houdremont. (*Arch. Eisenhüttenwesen*, 1956, **27**, Apr., 241–257). The authors describe investigations of the structure of sub-eutectic cast iron quenched from the temperature range 1350–1100° C. Specimens treated with magnesium were examined as well as untreated specimens, their composition being 1·5, 1·9, or 2·3% C and about 2·5% Si, 0·35% Mn, 0·04% P, and 0·02% S. Conclusions are drawn in the light of the experimental results and a survey of previous work.

The Identity of the Cubic Oxide Present in Films on Iron. D. E. Davies and U. R. Evans. (*J. Chem. Soc.*, 1956, Nov., 4373–4375). X-ray and electron diffraction studies show that iron develops films approximating to γ-Fe_2O_3 at room temperature and to Fe_3O_4 at higher temperatures. Lines characteristic of the former appear during its formation from Fe_3O_4 when about 80% is transformed. Possibilities of oxidation or reduction in the isolated films are discussed.

On the Mechanism of Graphite Crystallization in Hypereutectic Iron. E. Feil. (*Giesserei*, 1956, **43**, June 7, 315–318). A chemical investigation of the principal constituent of kish graphite indicated that this was far from pure. A metallographic investigation of the formation of graphite using an electron microscope yielded some remarkable results. Similarly an investigation was made of phosphide formation.

On the Crystallization of Graphite in Cast Iron. I. Karsay. (*Acta Techn.*, 1956, **15**, (1–2), 99–125). [In English]. The literature relating to the subject is reviewed, and the experimental work of the author is described in detail. A fourth, hitherto unknown mode of crystallization is described, resulting in the formation of hollow spherical shells of graphite. The mechanism of their formation on the walls of small gas bubbles in the metal is discussed, and micrographs of isolated shells are shown.—P. F.

The Kinetics of Grain Boundary Nucleated Reactions. J. W. Cahn. (*Acta Met.*, 1956, **4**, Sept., 449–459). Rate laws are derived for reactions in which the new phase originates on grain boundary surfaces, grain edges or grain corners and the limits are developed under which a particular site will be favoured. Constant or variable nucleation rates are considered.

Saturation Moments and *d*-Band Configurations in Iron and its Alloys. B. R. Coles and W. R. Bitler. (*Phil. Mag.* 1956, **1**, (8th series), May, 477–486). The effect of Al in Fe–Co alloys is investigated.

Improved Apparatus for Cutting Single Crystals. R. Piontelli, B. Rivolta and G. Sternheim. (*Rev. Sci. Instruments*, 1955, **26**, Dec., 1207). A chemical method using a plastic thread is described which imparts no distortion or strain.

Demonstration of Polygonization in Iron by Phase Interference Contrast. G. Cizeron and P. Coulomb. (*Compt. Rend.* 1956, **243**, Oct., 8, 1037–1040). Surfaces of iron specimens of various purities and after various treatments were electropolished and examined by phase contrast. Polygonization is much more readily seen than with an ordinary microscope.

Microdeformation of the α-Iron Lattice in Quenched and Annealed Steel. B. Ya. Pines. (*Doklady Akad. Nauk. SSSR*, 1955, **103**, (4), 601–604). Specimens quenched from 960° and annealed for 1 h at temperatures between 250° and 600° were examined with X-rays and the fine structure of the lines examined by a method previously described by the author.

Precision Measuring Metallurgical Microscope. A. G. Guy and A. S. Yue. (*Rev. Sci. Instruments*, 1956, **27**, Apr., 239–240).

Reflexion Electron Microscopy: Low-Angle Beam, High-Angle Observation. C. Fert, B. Marty and R. Saporte. (*Compt. Rend.*, 1955, **240**, May 16, 1975–1978). An account of a method by which good resolution of the image is still obtained and the relief is improved in reflexion electron microscopy.

Direct Carbon Replicas from Metal Surfaces. E. Smith and J. Nutting. (*Brit. J. Appl. Phys.*, 1956, **7**, June, 214–217). Two methods are described for the removal of carbon replica films directly evaporated on to etched metal surfaces. Films removed by electropolishing give replicas of high resolution whilst those removed by chemical etch after deposition of carbon may be prepared from multiphase alloys and the extracted phases identified by electron diffraction.—E. E. W.

The Determination from a Micrograph of the Amount and Distribution of the Constituents. An Example of the Application of Statistical Methods. J. Gélain. (*Fonderie*, 1956, May, 198–200). The use of simple statistical methods for determining the amount or distribution of a phase present in a microstructure is illustrated by reference to two practical examples involving the amount of cementite and the distribution of graphite in two microstructures.—B. C. W.

Vibratory Polishing of Metallographic Specimens. F. M. Krill. (*Metal Progress*, 1956, **70**, July, 81–82). An account of a new polishing machine having a vibrating polishing head in place of the more conventional rotating head is given. The machine has been used with aluminium alloys but it is hoped to develop its use for ferrous alloys.—B. G. B.

A New Etching Reagent for Steel and Cast Iron. B. V. Guellard. (*Metallurgia*, 1956, **54**, Aug., 93–96). An illustrated account of the use of sodium bisulphite solution as an etching reagent for steel is presented. Apart from its value as a general etching reagent it can also be used to reveal phosphorus-rich areas and chemical segregation at the grain boundaries. A number of photomicrographs illustrate the application of the techmique.—B. G. B.

Studies on Crystal Boundaries in Deformed Metals, Especially by Microhardness Measurements. H. E. Tuchschmid. (*Promotionsarbeit Eidgenössischen Technischen Hochschule in Zürich.* No. 2327, 1954, pp. 50). Crystal boundary precipitation was produced in a hot-rolled chromium–nickel steel and micro-tensile and microhardness measurements recorded. In general, the inadequacy of the techniques and also of X-ray and etch figure methods is stressed and measurements on single crystals or observations of individual grains are advocated.

The Appearance of Superficial Microstructures in Iron–Chrome Alloys Subjected to Selective Oxidation. J. Moreau and J. Bénard. (*Compt. Rend.*, 1955, **241**, Nov. 28, 1571–1573). This is a study of selective oxidation in steam of iron–chrome alloys analogous to one carried out by the authors on nickel–chrome alloys. The test-samples contained 2·6 to 45% Cr. The surface effects were studied with an electron microscope and were found to be related to the partial pressure of the steam. The oxidation was carried out at 1200° C.—G. E. D.

The Preparation in the Polygonized Form of Polycrystalline Test-pieces from Iron of Different Purities. J. Montuelle. (*Compt. Rend.*, 1955, **241**, July 11, 204–205). With suitable heat treatment followed by cold drawing at a given rate, it is shown that high purity irons show a polygonized sub-structure induced by tensions which manifest themselves at a temperature close to that of the $\gamma - \alpha$ transformation. The aptitude for polygonization depends directly on the purity of the metal being studied.—G. E. D.

On the Conditions under which the Increased Growth of Crystals Occurs in Soft Iron. P. Coulomb and P. Lacombe. (*Compt. Rend.*, 1955, **241**, Aug. 1, 494–496). The growth of large grains in soft iron of the Armco type seems to be due largely to the formation of a separate phase, which remains to be defined. The structure recalls those seen in electrolytic copper, Al–Mn alloys and impure aluminium.—G. E. D.

Investigation of the Textures arising from the Rolling and Recrystallisation of Carbonyl Iron. F. Haessner and H. Weik. (*Arch. Eisenhüttenwesen*, 1956, **27**, Mar., 153–160). Textures arising from rolling and recrystallization on straight- and cross-rolled plates were examined. The polar diagrams ob-

tained are compared with those of previous investigators. The effects of heat treatment and deformation on the development of recrystallized texture, and the elimination of rolled texture, are among the matters discussed.

Contribution to the Study of a Property of Polygonized State of Iron. J. Montuelle. (*Compt. Rend.*, 1955, **241**, July 25, 411–412). The stability of the polygonized state of iron, even after gentle drawing, is shown by the impossibility of preparing by the method of critical drawing large crystals from a test-piece of polycrystalline iron.—G. E. D.

Investigation of the Mechanism of Development of Annealed Steels by Electron Microscopy. N. V. Kazakova and N. V. Koroleva. (*Doklady Akad. Nauk SSSR*, 1955, **106**, (6), 1233–1235). Greatly enlarged micrographs are shown of separation of a new phase at grain boundaries from quenched 35 Kh NZ steel after annealing at 450–600° for 5 hours, with impact test figures.

Electron Microstructures of Bainite and Tempered Martensite in Steel. D. M. Teague and S. T. Ross. (*Amer. Soc. Test. Mat. Proceedings*, 1955, **55**, 590–622). S.A.E. 1087 steel is shown quenched and tempered at various temperatures.

Possibilities of the Study of Structural Transformations by Cinemicrography at Various Temperatures. P. Azou and A. Kerleroux. (*Métaux–Corrosion–Indust.* 1956, **31**, May, 244–249). Equipment used for studying the transformation occurring during the heating of metals is described. Results obtained during the study of the precipitation of carbides in non-stabilized 18/8 stainless steel and 25/20 stainless steel heated to 800° C are shown, and illustrate the potentiality of the technique.—B. G. B.

Retained Austenite in Slow-cooled Low-carbon Steels. C. C. Hsiao. (*Acta Met.*, 1956, **4**, July, 440–441). [In English]. Evidence obtained from electron diffraction microscopy is presented in support of the suggestion that austenite exists between ferrite grain boundaries in steel containing 0·05% C.

Effect of Compression on the Transformation of Austenite to Martensite. A. I. Stregulin and N. P. Chuprakova. (*Doklady Akad. Nauk SSSR*, 1955, **105**, (6), 1241). Apparatus is shown for subjecting specimens to pressures up to 1200 kg/cm² and steels 70G4N4 and 40GN20 were studied by putting under compression and cooling to the Tm point. Results are shown graphically.

Isothermal Decomposition of Austenite in Steels Containing Tungsten. (Part II). The Effect of Tungsten on the Isothermal Decomposition in the Steel 35Cr2V. J. Ćadek. (*Hutnické Listy*, 1956, **11**, (7), 409–419). [In Czech]. S-Curves were obtained for four steels, each containing 0·37% C, 1·75% Cr, 0·23% V and either 0·00, 0·38, 0·98 or 1·57% W. Thermomagnetic, metallographic, X-ray, and microchemical methods were used to study and isolate the carbide phases resulting from the decomposition, which took place either at 900 or at 1300° C. Two minima were observed in the stability in the ferrite–pearlite range in the two steels with the highest tungsten contents presumably due to two reactions. The bainitic reaction was studied. In this region high-austenitizing temperatures are reflected in comparatively high austenite stability. The effect is ascribed to the relation between the number of nuclei formed and the austenizing temperature. The Bs-temperature decreases with increasing tungsten content; the Ms-temperature remains essentially unaffected. Additions of about 1% of tungsten begin to have an effect on the stability of the austenite. The effect is not great, but the temperature domain of stability is considerably increased. Lesser amounts of tungsten are less effective. The effect of the austenitizing temperature on austenite stability in the ferrite–pearlite range increases uniformly with tungsten content. A comparison of the effect of tungsten on the austenite stability in the steels 18CrNi4, 25MnCrV, 35CrV2 shows that from the point of view of hardenability W–Ni–Cr combinations are best, alloying with W–Mn–Cr being somewhat inferior.—P. F.

Investigation of Crystal Fine Structure of γ–Phase Stabilized by Reversed Martensite Transformation. Ya. M. Golovchiner and R. A. Landa. (*Doklady Akad. Nauk SSSR.*, 1956, **107**, (1), 67–70). Studies on Super-Invar 32% Ni, 4% Co are described at high and low temperatures — 200 – + 750° C.

Martensitic Transformation in Binary Titanium Alloys. Y. C. Liu. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Aug., Section 2, 1036–1040). The author has investigated the habit plane of martensite and the orientation relationship between the matrix and martensite platelets of different habit planes in binary alloys of titanium with Mo, Cr, and Fe. The effect of the mode of deformation on the martensite habit plane is considered, and a micrograph of an exposed martensite platelet is presented.—G. F.

The Effect of Some Common Alloying Elements on the Breakdown of Martensite in a W.Q. 0·35% Carbon Steel. A. S. Kenneford and T. Williams. (*J. Iron Steel Inst.*, 1957, **185**, April, 467–474). [This issue].

The Bainite Transformation. R. F. Hehemann and A. R. Troiano. (*Metal Progress*, 1956, **70**, Aug., 97–104). A critical review is presented of published data on the bainite transformation and this is assessed in the light of recent findings. Although similar in characteristics to the martensite transformation the slow rate of propagation of individual plates indicates that diffusion-controlled processes must have an important role in the mechanism. (66 references).—B. G. B.

Characteristics of the Bainite Transformation in a Ni–Cr Steel. L. S. Birks. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Aug., Section 2, 989–993). Using an X-ray spectrometer, the author has investigated the austenite–bainite transformation in a 3½% Ni–1¼% Cr steel for both isothermal and continuous cooling conditions, with and without stress. The characteristics of the transformation are discussed, leading to a method of predicting the amount of transformation to be expected at a given temperature for any type of cooling curve.—G. F.

Intermetallic Compounds in Binary Systems. A. Krupkowski. (*Bull. Acad. Polonaise Sci.*, 1956, **4**, Class 4, (1), 45–50). A thermodynamic discussion.

The Effect of Silicon on the Solubility of Nitrogen in Alpha and in Gamma Iron. R. Rawlings. (*J. Iron Steel Inst.*, 1957, **185**, April, 441–449). [This issue].

Electrolytic Separation of Intermetallic Iron–Zinc Compounds, and Determination of Solubility of Some Metals in These Compounds. D. Horstmann and H. Malissa. (*Arch. Eisenhüttenwesen*, 1956, **27**, July, 423–428). The electrolytic process developed by Klinger and Koch was used to separate iron–zinc compounds from a matrix of zinc. The electrolyte used contained nearly 5% sodium citrate, 5% zinc sulphate, and phenacetin inhibitor. Sn, Cd, Cu, Sb, and Al inclusions in the separated crystals were microchemically determined. The saturation limits for some of these metals in the iron–zinc compound are given.

On the Activities of Si and C in Molten Fe–Si–C alloys. M. Ohtani. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1955, **7** Oct., 487–501). The activities of silicon and carbon in Fe–Si–C alloys were determined electrochemically and isoactivity lines of each solute were shown on the ternary diagram. The solubility of graphite in these alloys was established and the occurrence of silicon carbide in the higher range of silicon concentration was looked into. The mechanism of the increase of the activity of each solute on the addition of the third element is discussed.—J. G. W.

Activity Coefficient of Copper in Liquid Iron, Fe–C, and Fe–C–Si Alloys at 1600° C. P. J. Koros and J. Chipman. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Aug., Section 1, 1102–1104). The authors have studied the distribution of copper between liquid silver and liquid iron, Fe–C, and Fe–C–Si alloys at 1600° C. From the data and the activity of copper in silver obtained from phase diagrams, the activity coefficients of copper in iron up to 3% (atomic) are $\log \gamma_{Cu} = 0{\cdot}90 - 2{\cdot}4\ N_{Cu}$, and $\gamma°_{Cu} = 8{\cdot}0$. The effect of carbon up to saturation is expressed as $\log \gamma^{(c)}_{Cu} = 1{\cdot}8\ N_c$, and the effect of silicon up to 11% (atomic) is insignificant.—G. F.

Activity Coefficient of Copper in Liquid Iron at 1600° C. F. C. Langenberg. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Aug., Section 2, 1024–1025). By studying the distribution of copper between pure iron and lead at 1600° C, the author has calculated the activity coefficient of copper in iron at infinite dilution at 1600° C to be 8·8.—G. F.

Microstructure of Iron–Sulfur Alloys. A. S. Keh and L. H. Van Vlack. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Aug., Section 2, 950–958). Using experimental melts of iron and iron sulphide, the authors have examined the microstructures of the alloys and observed a variety of sulphide distributions depending on the sulphur content and cooling rate. The effects of heat treatment and

of additions of silicon, aluminium, manganese, and oxygen are discussed and illustrated, and certain phenomena of hot shortness are explained in terms of the microstructure.—G. F.

Austenitic Fe–Cr–C–N Stainless Steels. G. F. Tisinai, J. K. Stanley, and C. H. Samans. (*Trans. Amer. Soc. Metals*, 1956, **48**, 356–367). Combined additions of carbon and nitrogen can convert steels containing 21–33% Cr to a completely austenitic structure at temperatures of 2200° F and higher. Rapid cooling to room temperature will prevent its decomposition to ferrite, carbides and nitrides. The austenite exhibits a high degree of work hardening in addition to high tensile and yield strengths.—E. E. W.

Solubility of Hydrogen in Iron–Carbon–Silicon Alloys. V. B. John, and T. Evans. (*Found. Trade J.*, 1956, **101**, Aug. 23, 189–196). Previous work on the solubility of hydrogen in iron is briefly reviewed and a description is given of the apparatus and method used to determine the solubility of hydrogen in certain iron–carbon, iron–silicon, and iron–carbon–silicon alloys at temperatures between 600° and 1000° C. It was found that silicon decreased hydrogen solubility in both iron and iron–carbon alloys. Graphite was formed in the ternary alloys, during heat-treatment of the specimens and it appears that the presence of graphite slightly increased the hydrogen solubility.—B. C. W.

Investigation of Wrought Iron–Chromium–Aluminium Alloys Containing Platinum and Palladium. H. A. Saller, J. T. Stacey, and S. W. Porembka. (*AEC–BMI–1017*, 1955, pp. 21; *T.I.D.U. List* 451). Iron–25 w/o Cr–5 w/o Al alloy is increased in oxidation resistance by small amounts of Pt or Pd and in its stress-rupture strength at 1800° and 2200° F. Additions of Nb, Mo, Ta, and W had varying effects.

An Intermetallic Phase Having α–Manganese Structure in an Austenitic Chrome–Nickel–Molybdenum Steel with Increased Titanium Content. W. Koch and C. Ilschner-Gensch. (*Arch. Eisenhüttenwesen*, 1956, **27**, July, 453–457). An unfamiliar phase, rich in Mo and Ti was found in a steel containing 0·02% C, 16·8% Cr, 1·0% Mo, 9·6% Ni, and 3·1% Ti. This was electrochemically separable and accessible to microchemical and radiographic analysis. It was seen to be a uniform intermetallic phase having an α–manganese structure. The Ti and Mo contents had been enriched compared with those of the matrix metal, and there was also Fe, Cr, and Ni present. The new phase was dissolved in the matrix on heat treatment at and above 1100° C. In a steel with slightly higher Ti and Mo contents, an additional Fe_2Ti structural component was observed alongside the new phase. Fe_2Ti was found to be more stable than the new phase above 1000° C and was the only intermetallic combination observed above 1200° C.

The Structure of $FeCu_2Al_7$ and *T* (CoCuAl). M. G. Bown and P. J. Brown. (*Acta Crystallographica*, 1956, **9**, Nov. 10, 911–914).

CORROSION

An Approach to the Corrosion Problem. A. de S. Brasunas. (*Corrosion Techn.*, 1956, **3**, Aug., 261–265). The author defines corrosion and introduces the principles of anodic and cathodic corrosion. The reporting of corrosion rates is discussed and the confusion that at present exists in corrosion nomenclature is shown. The author concludes with a brief consideration of the various possible methods of mitigating corrosion.—L. E. W.

Corrosion, and the Protection Against Corrosion, of Iron and Steel. H. Klas and G. Heim. (*Stahl u. Eisen*, 1956, **76**, Apr. 5, 413–417). In the last of a series of articles on corrosion and its prevention, the authors review the literature of 1952–53 on non-metallic inorganic and organic coatings.

The Work of the Corrosion Section at Fulmer Research Institute. (*Metal Finishing J.*, 1956, **2**, May, 157–159). A brief account is given of the equipment available at the Fulmer Research Institute and of investigations recently carried out.—A. D. H.

Some Economic Aspects of Corrosion. A. Keynes. (*Corrosion Techn.*, 1956, **3**, July, 226–227). The author discusses very broadly the preliminary stages of a project concerned with research into some of the economic aspects of corrosion. This leads to a brief consideration of the balance of payments question and the significance of corrosion in companies' budgets.—L. E. W.

Effect of the Surface State and Structure on the Activity of Stainless Steels. H. Hatwell. (*Rev. Mét.*, 1956, **53**, Oct., 729–756). Results obtained during the study of the passive state of iron-chromium alloys under vacuum are discussed. The dissolution potential of surfaces exposed to a vacuum is compared with the potential of a surface treated in an inert atmosphere. A new aspect of the selective corrosion of stainless type steels, called 'honeycomb corrosion', has also been investigated.—B. G. B.

Mill Control of Corrosion. (*Brit. Steelmaker*, 1956, **22**, Oct., 298). An account of the Vacu-blast unit for mill scale removal which might be used in the mill.

The Tin–Steel Couple in Air-Free Citric Acid Solution. E. L. Koehler. (*J. Electrochem. Soc.*, 1956, **103**, Sept., 486–491). The corrosion mechanism of the tin–steel couple in 0·2 M citric acid solution was studied. All factors which caused variation in corrosion rates were shown to be the result of variation in anodic properties.—A. D. H.

Corrosion of Stainless Steel in Ferric Chloride Solution. H. A. Liebhafsky and A. E. Newkirk. (*Corrosion*, 1956, **12**, Feb., 48–54). Severe pitting of 18–8 stainless steel in 10 per cent ferric chloride solution can occur without much attack on the surface. Corrosion rate curves have been obtained which, coupled with radiographic and visual inspection, suggest that the surface forms the cathode and that the corrosion rate is proportional to cathode area.—J. F. S.

Effect of Hardening and Tempering on the Corrosion Resistance of 13%-Cr Steel. E. A. Oldfield and G. B. Graves. (*Metal Treatment and Drop Forging*, 1956, **23**, June, 211–215). An equation is given connecting tempering conditions to acid-resistance.

Stress Corrosion of Austenitic Stainless Steels in High Temperature Waters. W. L. Williams and J. F. Eckel. (*J. Amer. Soc. Naval Eng.*, 1956, **68**, Feb., 93–104). The article is a condensed version of a chapter in a forthcoming book with special reference to water-cooled nuclear reactors. Theory, previous literature, tests, and findings are all briefly discussed and illustrated.

Stress Corrosion Cracking of Stainless Steel. G. Klingel. (*Metal Progress*, 1956, **69**, Apr., 77–78). Removal of the thin surface layer after heat treatment of hardened stainless steel parts can prevent stress-corrosion failures.—B. G. B.

Methods of Evaluating the General Corrosion Stability of Stainless Steel Welded Joints in Boiling Nitric Acid. B. I. Medovar and N. A. Langer. (*Zavodskaya Laboratoriya*, 1955, **21**, (8), 941–944). [In Russian]. Electrolytic etching in a 10% oxalic acid solution has been used to reveal the microstructure of stainless steel and stainless steel welded joints. For the former 12 V is applied for 5 min, the corresponding figures for joints being 5 V and 0·5 min. Details are given of the cell used. Microstructural results for various steels boiled for 200 h in 55% nitric acid and for electrolytically etched specimens with previous heating to 650° C in some cases are presented. Comparison of the photomicrographs with corrosion test results indicate that the electrolytic etching technique can give a preliminary evaluation of corrosion stability in boiling nitric acid.—S. K.

Effect of Tempering Temperature on Stress-Corrosion Cracking and Hydrogen Embrittlement of Martensitic Stainless Steels. P. Lillys and A. E. Nehrenberg. (*Trans. Amer. Soc. Metals*, 1956, **48**, 327–355). Beam type specimens of stainless steels, types 410, 420, 422, and 436, tempered at various temperatures in the range 300–1200° F, were stressed by bending and then exposed to a 5% NaCl spray or arranged as cathodes in an electrolyte of 0·1% H_2SO_4 + 3 mg As/litre. Minimum susceptibility to cracking by hydrogen embrittlement occurred when the tempering had been done at 500° F, while the maximum occurred after a temper of 800–1000° F.

Effects of Chemical Composition and Heat-Treatment upon the Microstructure and Corrosion Resistance of AISI Types 309 and 310. D. J. Carney and E. R. Rosenow. (*Trans. Amer. Soc. Metals*, 1956, **48**, 456–473). The effects of variation in the C and N contents on intergranular corrosion resistance were investigated by immersion in boiling 65% nitric acid and copper sulphate–sulphuric acid.—E. E. W.

Corrosion and its Prevention at Bimetallic Contacts. (*Inter-Service Metallurgical Research Council*, 1956, pp. 1–10). **Foreword**, A. J. Murphy. **Introduction**, U. R. Evans and V. E. Rance. Tables of B.S. specifications are given followed by a table of degree of corrosion in four classes: not increased, slightly increased, markedly increased, and combination inadvisable. Three stainless steels are matched against 13 other classes of metals.

The Prevention of the Corrosion of Ferrous Metals. J. C. Hudson. (*J. Inst. Elect. Eng.*, 1956, **2**, Feb., 84–88). Tests have been made by the Corrosion section of BISRA on specimens of numerous types of iron and steel exposed to corrosion by air, soil, or water, both in the bare condition and when protected in various ways, notably by paints and metallic coatings. The results of these tests are discussed, together with practical recommendations.—M. A. K.

The C.C.C. System of Marine Cathodic Protection. (*Corrosion Prevention and Control*, 1956, **3**, June, 53). Three illustrations with brief explanatory tests are given to show the most suitable types of cathodic protection for an active ship and for a jetty.—L. E. W.

Corrosion Prevention Practice. V. Electrolytic Derusting at Alperton. (*Corrosion Prevention and Control*, 1955, **2**, Sept., 46–48). Brief descriptions are given of the new alkaline and acidic methods of derusting which are now being carried out by De-Corrosion Processes at its Alperton plant.—L. E. W.

Inhibition of Metallic Corrosion in Aqueous Media. H. C. Gatos. (*Corrosion*, 1956, **12**, Jan., 39–48). The theory of metallic corrosion in aqueous media is briefly discussed as an introduction to a review of the various types of inhibition both organic and inorganic and the theories of the mechanisms by which they operate. (100 references).—J. F. S.

The Prevention of Corrosion During Storage and Transit. C. F. McCue. (*Sheet Metal Ind.*, 1955, **32**, Aug., 565–571). A survey is given of the main groups of temporary protectives and a guide to the proper selection is discussed.—A. H. M.

Methods of Preventing Corrosion in Sewerage Systems. E. Spindel. (*Corrosion*, 1956, **12**, Mar., 136t–140t). A review of methods at present in use in the U.S.A. for protecting sewers and pumping equipment from chemical and electrochemical attack. Mention is made of additives, ventilation, clay and plastic liners, protective coatings, and cathodic protection.

Field Practices for Controlling Water-Dependent Sweet Oil Well Corrosion. N.A.C.E. Technical Unit Committee T–1C. (*Corrosion*, 1956, **12**, Mar., 149t–153t). Replies to a questionnaire received from 19 oil companies are reported. Limits at which corrosion becomes detrimental are set by reference to water produced, iron concentration, coupon corrosion rate, reduction in wall thickness, and frequency of equipment failures. Devices for injecting inhibitors are considered and types of inhibitor are discussed. Accounts are given of the use of plastic coated and alloy steel tubing.

The Oxygen Concentration Cell as a Factor in the Localized Corrosion of Metals. W. Lynes. (*J. Electrochem. Soc.*, 1956, **103**, Aug., 467–474). The discovery, the environment which favours the development of oxygen concentration and its electrochemistry are reviewed. (98 references).—A. D. H.

The Influence of Elements Commonly Present in Steel on Zinc Corrosion. D. Horstmann, (*Metall*, 1956, **10**, Aug., 701–708). In connection with the problem of corrosion of steel containers used in hot-dip galvanizing, 42 steels were prepared containing various amounts of C, Si, Mn, P, S, Al, and Cu. The iron loss of specimens subjected to attack by molten zinc was determined as a function of time and temperature. It follows from the results quoted that the attack of steel by zinc is accelerated most by the C and Si present in the steel.—J. G. W.

Pitting Corrosion of 18 Cr–8 Ni Stainless Steel. M. A. Streicher. (*J. Electrochem. Soc.*, 1956, **103**, July, 375–390). Factors controlling pitting corrosion are reviewed. An electrolytic test was developed in which the number of pits formed depended on current density, the composition and temperature of the electrolyte, and on the composition and surface condition of the test piece. In sodium chloride and bromide solutions, resistance to pit formation in 18 Cr/8 Ni steel was increased by the addition of Mo and Si as alloying elements and by increase in nitrogen content. Grain boundaries rather than non-metallic inclusions were primary sites of pitting.—A. D. H.

Effects of Some Included Elements in Unalloyed Structural Steel St 37 on Corrosion in Various Media. F. Eisenstecken and W. Stinnes. (*Arch. Eisenhüttenwesen*, 1956, **27**, July, 469–474). The authors describe investigations of natural corrosion in country and industrial atmospheres, and corrosion in both sustained and periodic immersion tests in synthetic sea and tap waters. The effect of S up to 0·22%, Mn up to 0·7%, P up to 0·5%, and Cu up to 0·6% on weight loss in 27 months is reported.

Electrochemical Investigations of the Effect of Rolling and Heat Treatment Scale on Corrosion, and of the Pickling Process. F. Wever and H.-J. Engell. (*Arch. Eisenhüttenwesen*, 1956, **27**, July, 475–486). The behaviour of local couples is described. The electrical properties of certain oxides and their thermodynamic stability in aqueous solutions are considered, and current–density : voltage curves given for their dissolution in acids. The authors discuss the behaviour of local couples of metal–oxide in acid solution and the mechanism of the pickling process, pickling losses, the effect of local couples of metal–oxide on corrosion, and the effects of dissolved oxygen and pH value.

Literature Survey of Corrosion in Cooling-water Systems 1940–1953. H. F. McConomy. (*American Petroleum Institute, Preprint*, 1955, May 9, pp. 49). The references are classified and abstracts provided.

Contribution on the Problem of Etching Stresses in Ferrous Materials. V. Hauk, H. Möller, and F. Brasse. (*Arch. Eisenhüttenwesen*, 1956, **27**, May, 317–322). Experiments were carried out on iron and fine-grained steels (alloyed and unalloyed) to determine the effect of etching on the state of stress in a specimen. It was shown that the stresses in both loaded and unloaded specimens are affected.

The Mechanism of the Oxidation of Metal and Alloys at High Temperatures. J. Bénard. (*Métaux–Corrosion–Indust.*, 1956, **31**, July-Aug., 306–310). A short discussion of this mechanism is presented.—B. G. B.

Internal Oxidation Rate of Metals and the Logarithmic Equation. H. H. Uhlig. (*Acta Met.*, 1956, **4**, Sept., 541–554). The equation governing the oxidation rate of metals in the lower temperature range when thin films are formed is derived assuming control of the rate by electron flow from metal to oxide. The Rideal–Jones function for activation energy of oxidation is also derived and shown to apply approximately to iron.—A. D. H.

The Effect of Nickel Content and Furnace Atmosphere on the Scale Formed on Nickel Steels. K. Sachs. (*Metallurgia*, 1956, **54**, Sept., 109–114). The inner layer of the scale on nickel steels contains nickel-rich metallic particles in a wüstite matrix. The amount of metal in the scale decreases with increasing partial pressure of oxygen in the oxide and with falling nickel content in the base metal. The furnace atmosphere and the scale thickness determine the partial oxygen pressure at various levels in the scale and thus the nickel content of the metal phase.—B. G. B.

Stress Corrosion. K. Matthaes. (*Z. Metallkunde*, 1956, **47**, Jan., 37–42). The chemical and mechanical conditions leading to stress corrosion in steel and non-ferrous metals are discussed. In the case of trans-crystalline stress corrosion in steel, chemical stressing is the only significant factor. Stress-corrosion in heat-treated and electroplated steel is discussed.—L. D. H.

The Effect of the Dispersed Phase on the Corrosion of Iron by Soil. T. Markovic, B. Jazbec, and N. Plavsic. (*Werkstoffe Korrosion*, 1956, **7**, July, 385–390). This is a further theoretical contribution to knowledge of soil corrosion, based primarily on laboratory measurements. The latter show that the effects of sludges are governed by the size of the particles and the nature of the electrolyte. Any alteration in the number or size of the particles affects the distribution of oxygen within the corrosive medium and thus the corrosion of the iron buried in it.—J. C. H.

The Corrosion Resistance of Galvanic Coatings. A. Sloof. (*Chem. Week.*, 1956, **52**, Sept. 29, 715–719). [In Dutch]. The need for fundamental research on the corrosion of metal coatings is emphasized in this paper calling also for the allocation of ample funds for the purpose. The corrosion resistance of metals is discussed in reference to the polarization phenomena occurring at the relative electrodes, it being pointed out at the same time that accelerated tests have little value as compared with what happens under conditions of service. Failures generally can be ascribed to the applied coatings being of insufficient thickness.—F. R. H.

Corrosion Resistance of Stainless Thread Inserts in Aluminium and Magnesium Alloys. P. E. Wolfe. (*Product Eng.*, 1956, **27**, April, 176–179). The results of salt spray tests are given showing that no finish is needed on the insert. Flange and washer finishes are evaluated.

Improved Sampling Apparatus for Water Containing Dissolved Oxygen. J. E. Houlihan and P. E. L. Farina. (*Analyst*, 1956, **81**, June, 377–379).

Cathodic Protection. P. W. Heselgrave and P. A. Tracy. (*Indust. Heating Eng.*, 1956, **18**, Apr., 67–70; May, 109–112; July, 176–179; Sept., 239–242). This series of articles deals mainly with buried or immersed structures. Beginning with an elementary account of theory they go on to describe sacrificial anodes and power impressed current systems with an account of the measurements necessary for the design and installation of protective systems. Miscellaneous applications and economic factors are discussed in the last article.

Cathodic Protection Circuits. E. W. Schwarz and R. M. Wainwright. (*Trans. Amer. Inst. Elect. Eng., Part II. Applications and Industry*, 1955, **74**, 311–315). After outlining the underground corrosion problem, the authors discuss the theoretical approach using a laboratory cell, and deriving and analysing the equivalent electric network.—L. D. H.

Use of a Volatile Corrosion Inhibitor as a Preservative Medium. R. L. Le Mar. (PB 116324, 1953, pp. 75 *T.I.D.U. List* 568). The subject is discussed in general terms. Bibliography 1937–1953.

Inhibition of Iron Dissolution in Acid Solutions. C. V King and E. Rau. (*J. Electrochem. Soc.*, 1956, **103**, June, 331–337). The inhibition of the dissolution of cylindrical specimens of pure iron in 0·02 M HCl or 0·02 M $HClO_4$ each containing 0·06 M KNO_3 by oxidizing and chelating agents was studied. 0·01 M $K_2Cr_2O_7$ gave the best results alone, but its action was assisted by neo-cupferron. Carbon monoxide was not found to act as an inhibitor.—A. D. H.

Corrosion and its Prevention in the Mining Industry—Protection by Coal Tar Products. F. Eisenstecken. (*Werkstoffe Korrosion*, 1956, **7**, June, 309–321). The author begins with a general account of the rusting of cast iron and steel in mining plants and installations. He then discusses methods of preventing this and refers particularly to the use of coal tar products. Some proprietary plastic mastics of this type, sprayed on hot by a special pistol, are giving encouraging results.—J. C. H.

ANALYSIS

The Use of the Thermobalance in Analytical Chemistry. F. Claisse, F. East, and F. Abesque. (*Province of Quebec, Dept. of Mines, Lab. Branch*, P.R.305, 1954, pp. 11). A discussion of the instrument with as one example, the determination of goethite in iron ores.

Liquid–Liquid Extraction Procedures in Inorganic Analysis. T. S. West. (*Metallurgia*, 1956, **53**, Feb., 91–96; Mar., 132–134; Apr., 185–188; May, 234–236; 240; June, 292–294; **54**, July, 47–51; Aug., 103–106). Liquid–liquid solvent extraction techniques in inorganic analysis with particular reference to metallurgical analysis is reviewed in detail. (150 references).—B. G. B.

New Method of Investigation of the Chemical Composition of Alloy Microvolumes. I. B. Borovskiĭ and N. P. Il'in. (*Doklady Akad. Nauk SSSR.*, 1956, **106**, (4), 655–657). A reflexion electron microscopical apparatus with grating and recording system is described, capable of indicating Fe, Ni, Cu, Zn, Nb, Mo, W and Re quantitatively.

Polarography and Electrical Methods of Analysis. G. F. Reynolds. (*Research*, 1956, **9**, May, 170–183). Amperometric and coulometric methods are included in a review with 93 references.

The Rapid Analyses of Stainless Type Steels. J. Culberston and R. M. Fowler. (*Mét. Constr. Mécan.*, 1956, **88**, Apr., 359–365). Methods of analysis used for stainless type steels are discussed. Details are given of colorimetric procedures for the determination of Ni, Cr, and Mn which have been shown to be satisfactory in practice.—B. G. B.

Vacuum Wavelength Measurements in the Ultra-violet Spectrum of Iron. J. Blackie and T. A. Littlefield. (*Proc. Roy. Soc.*, 1956, **234A**, Feb. 21, 398–404). The light sources and optical system are described and the lines tabulated.

Catalog of Infra-red Spectra for Qualitative Analysis of Gases. R. H. Pierson, A. N. Fletcher, E. St. C. Gantz. (*Anal. Chem.*, 1956, **28**, Aug., 1218–1239).

A Review of the Uses of Radioisotopes in Industry. J. C. Rockley. (*Inspection Engineer*, 1956, **20**, Mar.-Apr., 26–29). Properties and characteristics of radioisotopes are given and tracer techniques are discussed.—A. H. M.

The Industrial Use of Radioisotopes. G. E. André. (*Rev. Soc. Roy. Belge Ing. Ind.*, 1956, Sept.-Oct., 370–387). A review of the use of radioisotopes in industry with particular reference to their use in Belgium. The fundamental principles of their applications are explained.—B. G. B.

Use of Radio-Isotopes in Materials Technology. K. Sauerwein. (*Metall*, 1956, **10**, May, 387–393). Various uses of radioactive isotopes are outlined, including gauging of strip, radiography, and tracer techniques for the study e.g. of impurities in cast steel, of decarburization of steel and of reactions in steelmaking.—J. G. W.

Association of ^{60}Co Ions with Metal Surfaces. R. T. Foley, B. T. Stark, and C. J. Guare. (*J. Electrochem. Soc.*, 1956, **103**, Oct., 534–538). A radiochemical technique for the study of surface reactions was investigated using Cobalt-60 radio-isotope which was found to be deposited from solution on surfaces by adsorption and electrolytic deposition. It is considered that since Co^{60} is preferentially deposited at cathodic areas, if the influence of surface oxide films on absorption is studied and recognized; the method could be used to study corrosion mechanisms.

Metallurgical Examination of Gamma-active Materials. B. W. Mott. (*Research*, 1956, **9**, Mar., 95–98). The preparation and examination of sections is described.

Statistical Studies of Coal and Ore Sampling. S. Moriguchi, T. Asaka, K. Ishikawa, and S. Aoki. (*Tokyo Univ. Fac. Eng. Annual Report*, 1954, 24–27, summary, 243–244). Size and number of samples and size of scoop are discussed.

Statistical Studies on Coal and Ore Sampling. S. Moriguchi, T. Asaka, K. Ishikawa, and T. Fujimori. (*Tokyo Univ. Fac. Eng. Annual Report*, 1955, 15–21). Ash content variation is discussed.

Selective Measurement of Gas Concentration in a Multicomponent Mixture. J. P. Strange. (*Iron Steel Eng.*, 1956, **33**, Aug., 158, 161–162). The thermal conductivity analyser is described. Hydrogen can be measured in furnace atmospheres.

INDUSTRIAL USES AND APPLICATIONS

Materials for Gears. R. Moussoux. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Sept., 350–359). The choice of steels for gears is dependent on their susceptibility to thermal treatment. Surface compressive stresses are of particular value in gears and explain the interest in cementation treatment. The advantages of surface tempering are discussed.

Steels for Springs and the Safety of Suspensions. A. Oreffice. (*Mét. Constr. Mécan.* 1956, **88**, June, 559–563). The selection of steels for vehicle suspensions is discussed. The influence of thermal treatment on the properties of spring steels is considered and details of steels which have been found satisfactory for various service conditions are given. The surface protection of suspensions against corrosion is also mentioned.—B. G. B.

Some Thoughts on the Use of Steel-Light Alloys in the Construction of Transport Vehicles. A. Ogus. (*Mét. Constr. Mécan.*, 1956, **88**, Apr., 373–378). The combination of light alloys and steel is shown to have considerable advantages in vehicle construction.—B. G. B.

Extreme Conditions of Use of Steel Pit-Cage Cable. M. Duruy. (*PACT.*, 1956, **10**, Feb., 55–74; Apr., 165–176; June, 248–256). After an outline of fabrication methods, the theoretical aspects of use, wear, and fracture of cables are examined in detail. Some information is given concerning conditions of use of steel cables, regulations relating to their use, and testing methods in the Saar, Ruhr, Belgium, Britain and South Africa. Similar, more detailed information is given for France.—T. E. D.

Flat Rolled Electrical Steel. (*Amer. Iron Steel Inst. Steel Prod. Man.*, 1956, Mar., pp. 87). Methods of manufacture are reviewed and gauges and tolerances given; types and magnetic properties are tabulated and standard testing methods for magnetic properties and ASTM specifications given.

Improvement of Permanent Magnet Alloys. T. Mishima and M. Mishima. (*Tokyo Univ. Fac. Eng. Annual Report*, 1954, 129–137). M.T. magnet steel, Cunife and Cunico alloys are described with heat-treatment studies and cold working effects. Decarburization and its prevention are discussed.

Boiler Chimneys, A. F. Webber. (*Steam Eng.*, 1956, **26**, Oct., 28). The cost and life of small brick and steel boiler chimneys are briefly discussed.—R. F. P.

Concerning Conductor Lines of Aluminium–Steel. L. Albert. (*Rev. Aluminium*, 1956, **33**, June, 615–619). Favourable opinions on the use of aluminium–steel wires are expressed in reply to an unfavourable expression at the Naples Congress, 1955. Less wear, reduced maintenance and

lower installation costs were incurred, in comparison with copper, in Paris transport undertakings.

Studies in Bomb Calorimetry VI. Steels for Making Calorimeter Bombs. R. A. Mott and I. Moulson. (*Fuel*, 1956, **35**, Oct., 476–492). The relative merits of carbon, martensitic and austenitic steels for this purpose are discussed. Austenitic steel of low carbon content is preferred and should contain molybdenum to prevent pitting and intergranular corrosion. Several bombs including 3 which failed were examined and a non-destructive ringing test has been developed. A specification for new bombs and precautions for old bombs are suggested.—B. G. B.

Nuclear Reactors Pose New Problems in Mechanical Design. (*Product Eng.*, 1956, **27**, Apr., 187–210). Materials, mechanical components and controls are reviewed. Effects of radiation on materials including steels are tabulated. Pump, valve, seal, and bearing designs are discussed and remote control methods are briefly considered.

HISTORICAL

Archaeological Researches Relating to Iron Extraction in Switzerland. W. U. Guyan. (*Stahl u. Eisen*, 1956, **76**, May 3, 618–619). The study is stated to be at its beginning, and a brief review is given of the present position.

Yesterday's Primitives. F. Evans. (*Brit. Steelmaker*, 1956, **22**, Aug., 232–234). The author traces the ironmaking history of the English Weald in the Middle Ages, and the design of the early furnaces is outlined.—G. F.

An Appreciation, Sir Henry Bessemer. 1813–1898. J. Almunia y de Leon. (*Inst. Hierro Acero.*, 1956, **9**, Apr.-June, 707–727). [In Spanish]. The life and inventions of Sir Henry Bessemer are described, and the effect upon industry of his invention of the converter is discussed.—P. S.

Turner's Iron-Fibred Steel. E. N. Simons. (*Brit. Steelmaker*, 1956, **22**, Sept., 260–263). A description is given of the development of Turner's iron-fibred steel, made by casting mild steel around various shapes and sections of wrought or worked iron or steel. The composite material was claimed to combine the strength of steel with the fibrous toughness of iron, and was marketed up to about 1930.—G. F.

Starting up a Steel Foundry in 1890. E. N. Simons. (*Metallurgia*, 1956, **54**, Sept., 128–131). An historical account of the cost of building the steel foundry of Edgar Allen and Co. Ltd. in 1890 and of negotiations which were carried out is given.—B. G. B.

ECONOMICS AND STATISTICS

Steel in West Germany. (*Times Rev. Indust.*, 1956, **10**, Aug., 77, 79). Mainly statistical discussion.

Estimation of Quantities and Costs in Planning the Production of a Mixed Steelworks. W. Bauer. (*Arch. Eisenhüttenwesen*, 1956, **27**, May, 347–354). The author describes how fluctuating requirements were absorbed by suitable planning. He discusses equations and diagrams used to calculate production limits and costs, and makes allusion to the use of electronic computers.

MISCELLANEOUS

Mechanization of Calculations in Metallurgical Research. E. M. Zamaraeva, K. T. Suvorov, K. V. Demŷkin, and A. L. Brudno. (*Stal'*, 1955, (12), 1124–1129). [In Russian]. This is a contribution to a conference held to discuss experience in the use of mechanized accounting and computing methods in the iron and steel industry generally. It gives details of some techniques involved and examples of successful application in the steel industry, with special reference to rail production.—S. K.

Reduction of Iron Oxides by Gases. Kinetic Equations for Reduction of Ferrous Oxide by Hydrogen. V. V. Kondakov and Z. F. Chukhanov. (*Doklady Akad. Nauk SSSR.*, 1956, **106**, (4), 697–700).

Magnetite in the Hurley Copper Smelter. H. W. Mossman. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Sept., 1182–1191). The author discusses the problem of magnetite in copper smelting and works out the equilibrium conditions of sulphur elimination. The influence of magnetite solubility on the difficulty of tapping the matte is considered, and an approximation is given to the equilibrium conditions in the reverberatory gases which govern whether magnetite is made or reduced in the slag by these gases and by any FeS present.—G. F.

Lattice Magnetostriction in Spinel-type Iron Chromites. M. H. Francombe and H. P. Rooksby. (*Nature*, 1956, **178**, Sept. 15, 586).

Magnetic Properties of Some Metal Carboxylates. R. C. Herron and R. C. Pink. (*J. Chem. Soc.*, 1956, Oct., 3948–3952). Iron laurate and stearate were examined and anomalously low values found with a very large Weiss constant.

Electrical Conductivity of Iron Sulphides Single Crystals at the Temperature Range of α–Transformation. T. Kamigaichi, T. Hihara, H. Tazaki, and E. Hirahara. (*J. Phys. Soc. Japan*, 1956, **11**, May, 606–607). An anomaly in the electrical conductivity of nearly stoichiometric samples of iron-sulphide single crystals, is reported corresponding to similar anomalies in magnetic, thermal and crystallographic properties.—J. G. W.

The Magnetic Properties of $FeSe_x$ with the NiAs Structure. T. Hirone and S. Chiba. (*J. Phys. Soc. Japan*, 1956, **11**, June, 666–670). Thermal and X-ray analyses of the Iron–Selenium system in the range 48·8–57·4 atomic % Se are reported, from which it is concluded that ferromagnetism of the system originates in the β-phase (of NiAs type), whilst the other phase is weakly paramagnetic or antiferromagnetic.—J. G. W.

The Raman Spectrum and Thermodyanmic Properties of Iron Pentacarbonyl. F. T. King and E. R. Lippincott. (*J. Amer. Chem. Soc.*, 1956, **78**, Sept., 4192–4197).

Exsolution of Titanomagnetite and its Time Effect on Rock-Magnetism. I. Change of Exsolution Phase with Geological Age. N. Kawai, S. Kume, and K. Yasukawa. **II. Correlation between Rock-Magnetism and Exsolution Phase.** N. Kawai, S. Kume, and S. Sasajima. **III. Effects of Enduring Temperature and Slow Cooling.** N. Kawai. (*Proc. Japan Acad.*, 1956, **32**, July, 455–458; 459–463; 464–468). [In English]. Volcanic rocks contain titanomagnetites with intermediate titanium contents. At the time of formation these exhibit thermo-remanent magnetism. On cooling, titanium-rich and titanium-poor magnetites are formed, which exhibit thermo-remanent or isothermal remanent magnetism, according to composition. Compositions tending to be stable at ordinary temperatures are postulated.—K. E. J.

Study of Magnetic Annealing on Ni_3Fe Single Crystal. S. Chikazumi. (*J. Phys. Soc. Japan*, 1956, **11**, May, 551–558). Magnetic anisotropy induced in a Ni_3Fe single crystal by magnetic annealing, was found to depend on the crystallographic direction of the field which is applied during annealing Observations are interpreted by reference to the Néel–Taniguchi–Yamamoto formula.—J. G. W.

Present Position of the Titanium Industry. (*Génie Civil*, 1956, **133**, July 15, 270–274). Data on titanium alloys are included compared with a stainless steel.

Vanadium. Its Minerals and Deposits. (*Génie Civil*, 1956, **76**, Nov. 1, 398–401). A review.

Are You Getting Good Returns from Your Ventilating Investment? A. D. Brandt. (*Iron Steel Eng.*, 1956, **33**, Sept., 92–100). Various unsuccessful installations are described with the improvements effected.

Energy Loss and Range of Electrons and Positrons. A. T. Nelms. (*National Bureau of Standards, Circular*, 577, 1956. July 26, pp. 30). Losses in iron are tabulated.

BOOK NOTICES

OSBORNE, A. K. "*An Encyclopaedia of The Iron and Steel Industry.*" La. 8vo, pp. xv + 558. Illustrated. London, 1956: The Technical Press, Ltd. (Price 90*s.*).

Miss Osborne's book, prepared with all the skill in the selection and presentation of information that have come from thirty years' experience in setting-up and running the Technical Library and Information Service of the Firth Brown Group, will be of much value to all levels of the industry. It contains 477 pages of definitions, including a most interesting page on the Oberhausen processes, supplied as the book was going to press, 30 pages of references, and several appendices of conversion tables, signs and

symbols and the names of scientific and technical societies. The encyclopaedia entries are not all of equal value, and many, such as " bill of entry ", " demy " (and other book sizes), " London Metal Exchange ", " notary public ", " Richards, Theodore William ", " theory ", " United Kingdom Scientific Mission ", are either superfluous or out of place, but all in all, comprising, as it does, definitions ranging from the colloquial, such as " compo ", to the scientific, such as " superlattice ", its value far outweighs its faults. The author must be congratulated upon a production which is certain to pass into many editions and occupy a permanent place in metallurgical literature.

J. P. S.

JONES, E. B. "*Instrument Technology.*" Volume II. "*Analysis Instruments.*" La. 8vo, pp. xi + 208. Illustrated. London, 1956: Butterworths Scientific Publications. (Price 40*s.*).

As stated by the author, this book is written to cover the appropriate section of the instrument maintenance syllabus of the City and Guilds of London Institute and also for works chemists who have to use particular instruments of these types. The book is a sequence to Volume I, which deals with pressure, flow, position, and temperature measuring instruments.

The first chapter deals with methods of sampling liquids and gases, and the remaining chapters give details of the principles of operation, construction and use of various makes of instruments. This information will be of particular value to people who have to use equipment of this type. For the instrument maintenance mechanic who is expected to trace faults and carry out repairs there are not many data which will help him in his work. It is considered that more detail on the methods of adjustment and calibration could also have been included with advantage.

As an example of what is missing, the section dealing with calorimetry, which is a very important one for the Iron and Steel Industry, gives a brief description only of the principle of operation of an inferential type of calorimeter. No mention is made of the General Notification of the Gas Referees regarding the use and checking of calorimeters nor of the makes of calorimeters which are approved by them. There is no information regarding checking and maintenance.

In general, it is thought that, whilst the book will prove quite useful to the instrument engineer, senior chemist, etc., by presenting him with data on the various instruments available for analysis, etc., it is far from being as useful as it could be for the training of an instrument maintenance mechanic.—R. A. KIPLING.

GROVER, H. J., S. A. GORDON, and L. R. JACKSON. "*Fatigue of Metals and Structures.*" (First Published in Great Britain 1956). 8vo, pp. x + 401. Illustrated. London, 1956: Thames and Hudson. (Price 35*s.*).

In 1941 the Battelle Memorial Institute produced a book on " Prevention of the Failure of Metals under Repeated Stress " primarily to help designers. This new book (published earlier in the U.S.A. and now in Great Britain), has been written by three authors from Battelle in order to survey the present state of knowledge and to provide additional help to the designer. In this they have succeeded admirably and the arrangement of the subject matter is a considerable improvement on that in the earlier book. Metallurgists will find particularly useful the exhaustive bibliography and what must be the most comprehensive tabulation of fatigue data available in one place. As in the earlier book, a large number of photographs are given of fatigue failures which have occurred in service.

The influence of stress conditions on fatigue strength naturally forms a considerable portion of the book. Chapters are included on scatter and dependability of fatigue test results, on fatigue damage and on statistical analysis of fatigue data. This reflects the modern requirement for more precise information of fatigue behaviour, so that working stresses may be increased. A chapter on methods of using fatigue data in design incorporates the novel idea of worked examples on the design of parts to withstand repeated stress conditions. These examples illustrate just how difficult it can be for the designer to ensure that fatigue failures do not occur.—P. G. FORREST.

BURTON, MALCOLM S. "*Applied Metallurgy for Engineers.*" 8vo, pp. ix + 407. Illustrated. New York, Toronto, London, 1956: McGraw-Hill Book Co., Inc. (Price 56*s.* 6*d.*).

The field of metallurgy for engineers is reasonably well catered for, but the present volume is justified, since it is certainly the most comprehensive and up-to-date book on this aspect of the subject.

The author has appreciated the fact that engineers require a sound knowledge of the fundamental principles of metallurgy and their application in present-day techniques. The sequence of subjects is most carefully chosen and a theoretical section usually precedes a group of chapters dealing with practical aspects of metallurgy.

Chapters 1 to 3 deal briefly, but adequately, with the nature of metals and alloys, metallographic techniques, testing machines and their application. The next chapter gives an account of equilibrium diagrams in sufficient detail for a subsequent appreciation of heat-treatment principles and techniques in Chapters 6 to 8.

Chapter 5 describes the production of metals in a form suitable for subsequent fabrication, and chapters 9 to 12 deal with the metallurgical fundamentals of foundry work, casting processes, foundry sands and moulding techniques, melting and pouring procedures.

Chapters 13 to 15 give an excellent account of the theory and techniques of mechanical working of metals and alloys. Chapter 16 discusses the theory of the bonding of metals to be applied in three subsequent chapters in studying the processes of soldering, brazing, welding and powder metallurgy. A useful section (Chapter 20) is introduced here dealing with gas and arc cutting of metals. The last chapter is concerned with powder metallurgy.

A list of reference books and a number of questions are suitably placed at the end of each chapter.

This volume is typically American, nicely bound, well printed on good paper and on sale at a moderately high price.—L. W. DERBY.

HAYWOOD, F. W. and A. A. R. WOOD. "*Metallurgical Analysis by Means of the Spekker Photoelectric Absorptiometer.*" 2nd edition. 8vo, pp. viii + 292. Illustrated. London, 1957: Hilger & Watts, Ltd. (Price 40*s.*).

The first edition of this very useful work on metallurgical analysis appeared in 1944, so that its revision is not untimely, in view of the advances in photo-electric techniques and improved apparatus that have been developed since that time.

Full details of the newer (*H*760) absorptiometer and transmission curves of all available filters are given, together with detailed accounts of operating the instrument. The various sources of inaccuracy, both chemical and physical, are discussed and commented upon.

The methods of analysis for aluminium alloys have been augmented to include lead, antimony, and magnesium and a much improved method for silicon has been substituted for dealing with alloys of high silicon contents.

The addition of a method for bismuth, using a chloroform extraction of the dithizone complex, and a very simple method for the determination of lead has considerably enhanced the value of the section on the analysis of copper alloys. Indeed, in this section, all the methods, except that for phosphorus, have been improved, and that for copper itself has rightly been omitted. On p. 131 under " Accuracy " there is an obvious error, and nickel should replace iron.

The section on steels contains much additional matter; methods for aluminium, lead, phosphorus, tungsten, and combined carbon are included, although the value of the latter is doubtful since, as the authors quite rightly state, the accuracy depends on various factors outside the control of the analyst. Most of the other methods described in this section are well-known, and frequent reference is made to the absorptiometric methods developed by B.I.S.R.A. and published in the *Journal of The Iron and Steel Institute.*

After methods for magnesium alloys and an extensive bibliography there is an interesting appendix on the diagnosis of faults in the absorptiometer.

The details given are very clear and concise, the methods are written up in a much better style than in the first edition and the book should appeal to both the beginner and the experienced analyst.—EDWIN GREGORY.

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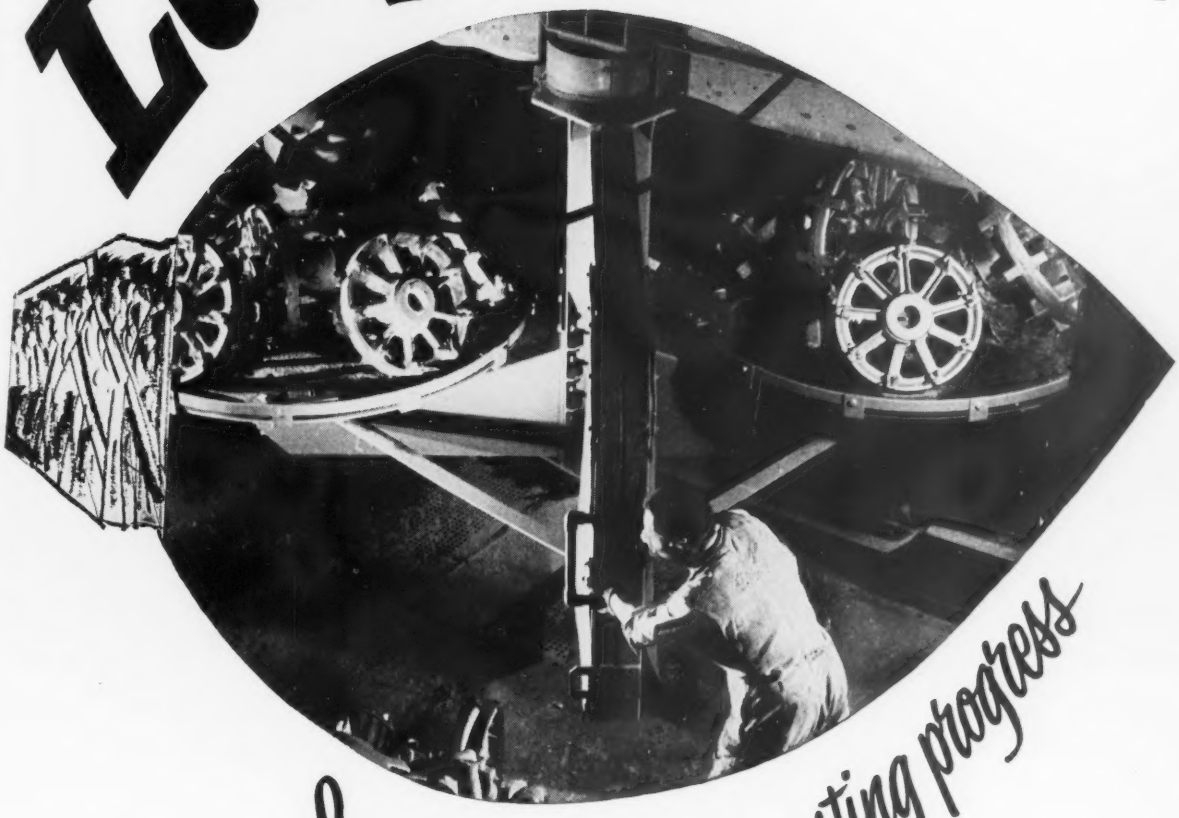

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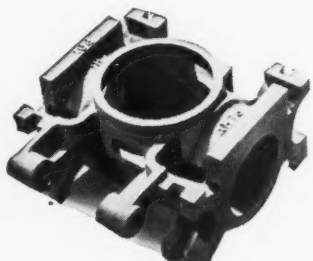

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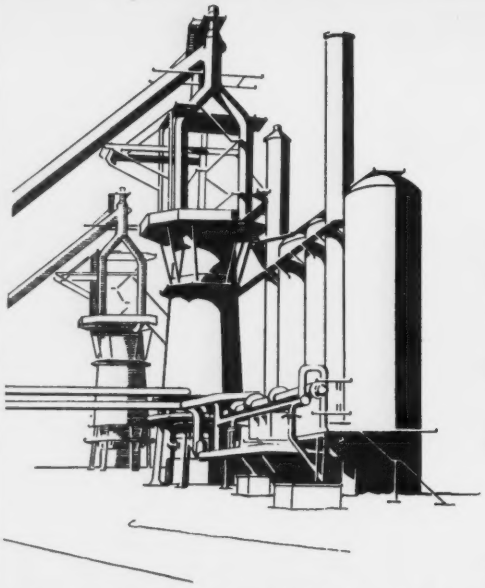

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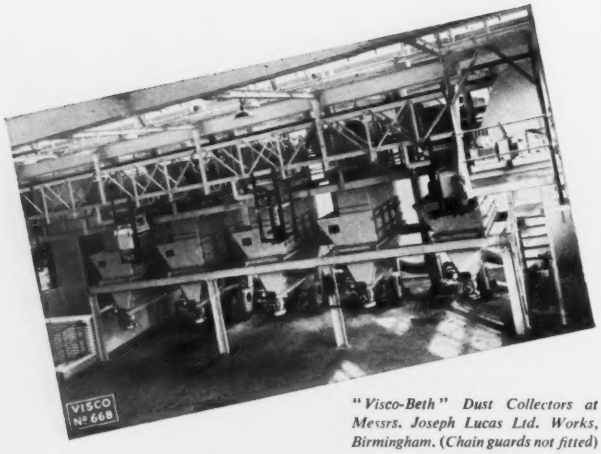

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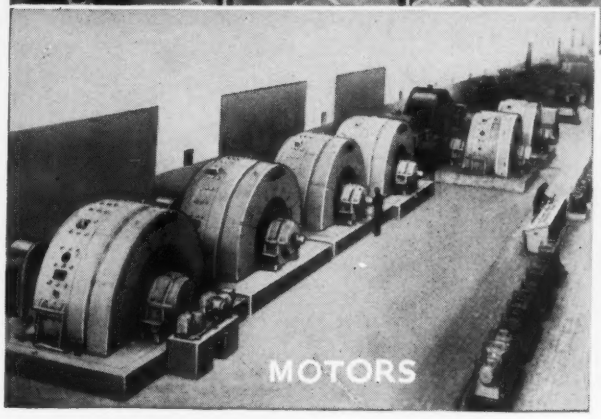

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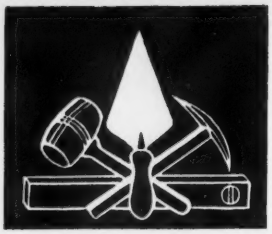

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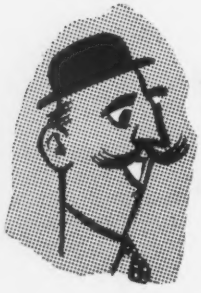

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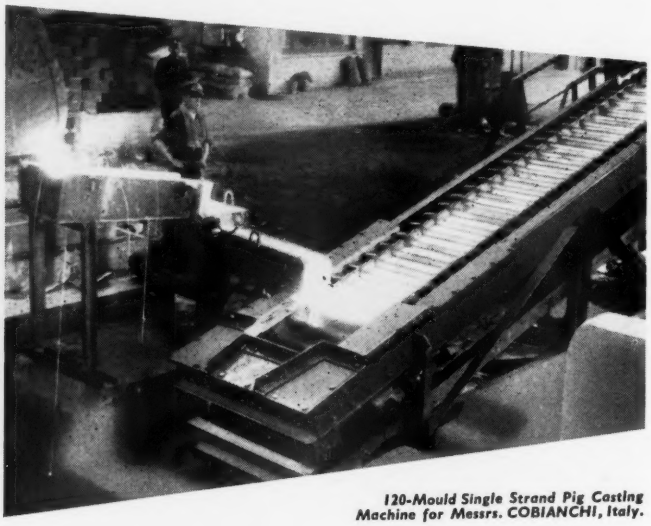

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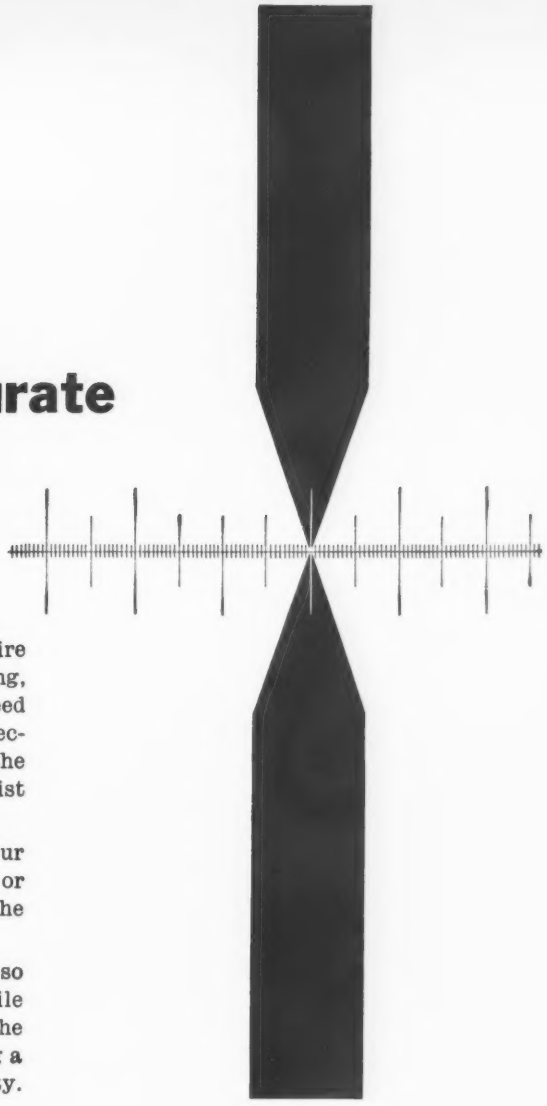

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THE IRON AND STEEL INSTITUTE

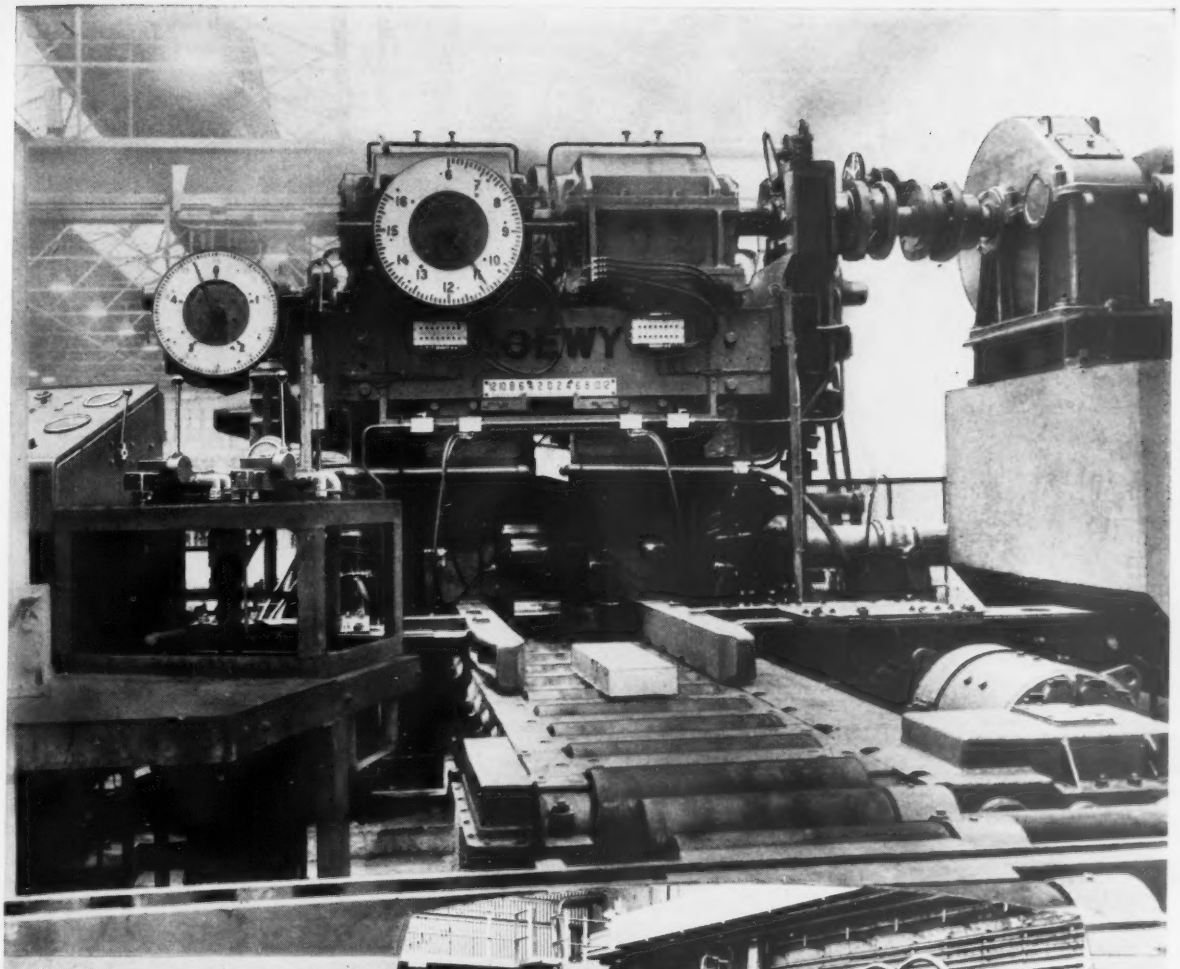
Special Report No. 59

COMBUSTION AND HEAT TRANSFER IN AN OPEN-HEARTH FURNACE

THE latest addition to the Special Report series of the Institute is entitled "Combustion and Heat Transfer in an Open-Hearth Furnace," by S. W. Pearson, M. W. Thring, and J. H. Chesters. This Report describes a large-scale trial carried out on a Templeborough furnace with a team consisting of groups from Messrs. Steel, Peech and Tozer, the Research and Development Department of the United Steel Companies Ltd., the University of Sheffield, and the British Iron and Steel Research Association.

The previous Templeborough trials, reported in Special Report No. 37 (1946), emphasized the necessity for aerodynamic studies, continuous roof-temperature measurement, and the maintenance of the highest practicable furnace pressure. The shift from producer gas to oil firing in the last ten years has added new objectives, e.g. the determination of optimum nozzle size, steam/oil ratio, and burner direction. The work of the International Flame Radiation Committee at Ijmuiden has given preliminary answers to some of the questions, whilst the theory of heat transfer initially expounded in Special Report No. 37 has been developed to a point where calculated melting times and fuel consumptions are of the same order as those found in practice. The main purpose of the present trial was to measure as many factors as possible, leaving only one free parameter in each verifiable part of the calculation; this could then be determined from the observed result and the value thus obtained used with some confidence in future calculations. A subsidiary objective was the comparison of flow pattern and mixing in model and furnace.

The Report, No. 59 in the series, is fully illustrated with diagrams and photographs and is bound in cloth with stiff board covers. Copies may be obtained on application to the Secretary, The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, price 37*s.* 6*d.* (Members 25*s.*).



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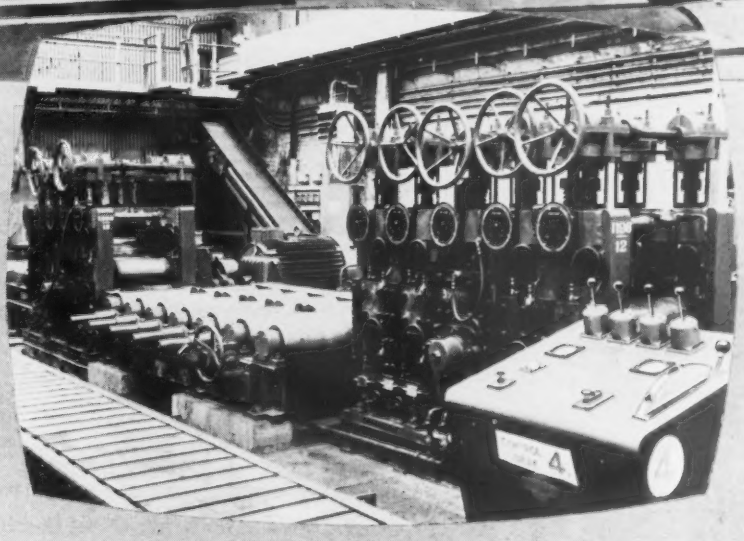

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THE IRON AND STEEL INSTITUTE

Special Report No. 60

Proceedings of the

FORGEMASTERS' MEETING, 1954

In October, 1954, The Iron and Steel Institute held a Joint Meeting with the National Forgemasters' Association and La Chambre Syndicale de la Grosse Forge Française. Technical Sessions were held in London at which nine papers on forging theory and practice and forging plant were presented and discussed. The remainder of the Meeting comprised visits to the English Steel Corporation Ltd., Thos. Firth and John Brown Ltd., and Hadfield Ltd., in Sheffield.

The Proceedings at the Technical Sessions have now been published as a Special Report. The five French papers and discussion are presented in English, but summaries of all the papers are also given in French. The Report, No. 60 in the Special Report series of the Institute, can be obtained from the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, price 37*s.* 6*d.* (Members 25*s.*).

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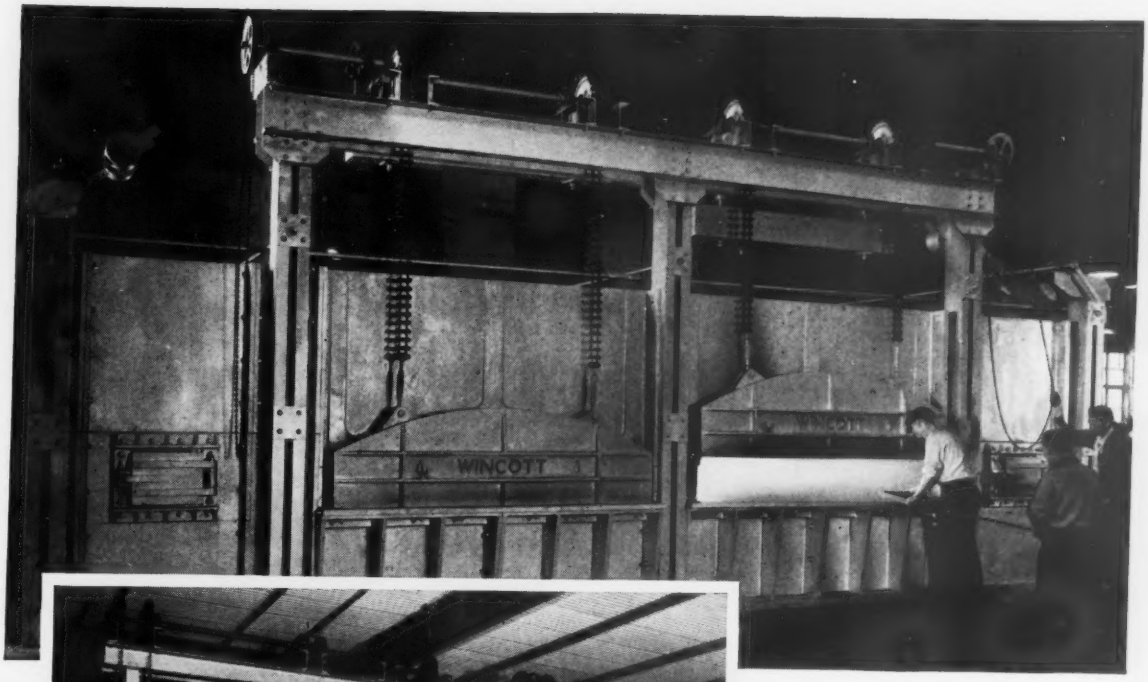

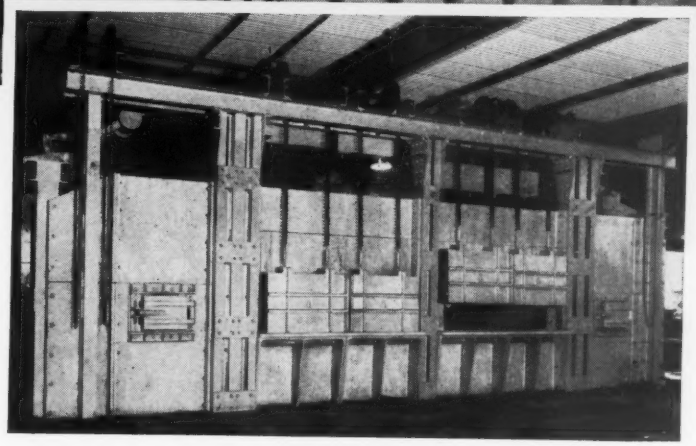

Above is a twin furnace with hearths 8′ 0″ wide by 9′ 0″ long, each fitted with a single door.
To the left is a twin furnace with hearths 6′ 0″ wide by 8′ 0″ long, each fitted with double doors.

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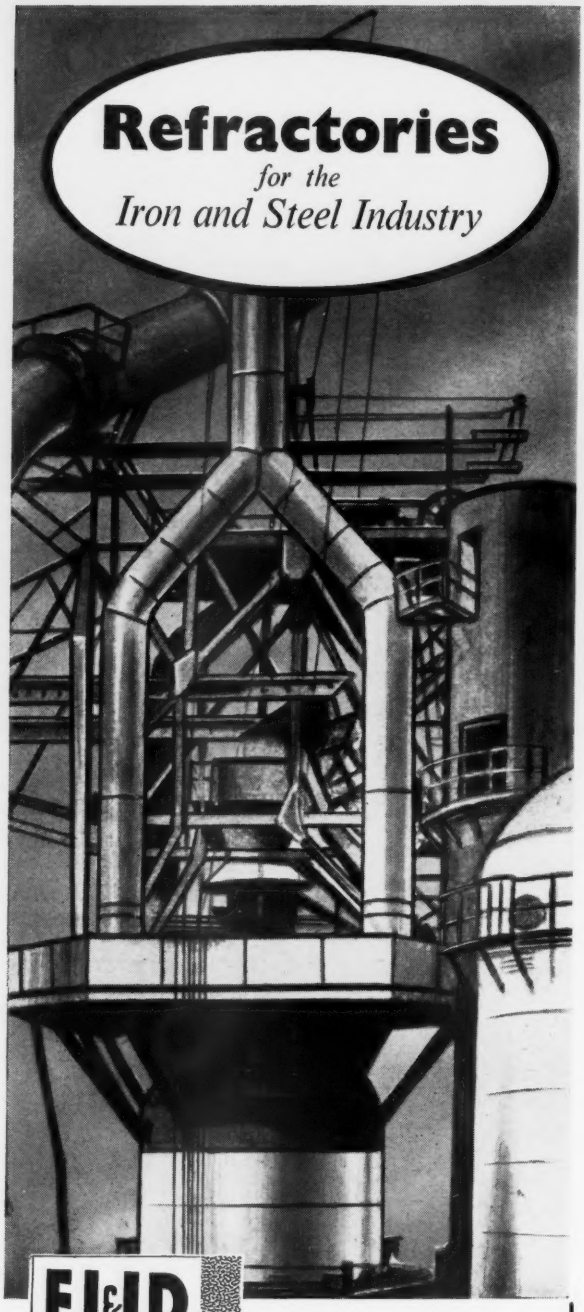

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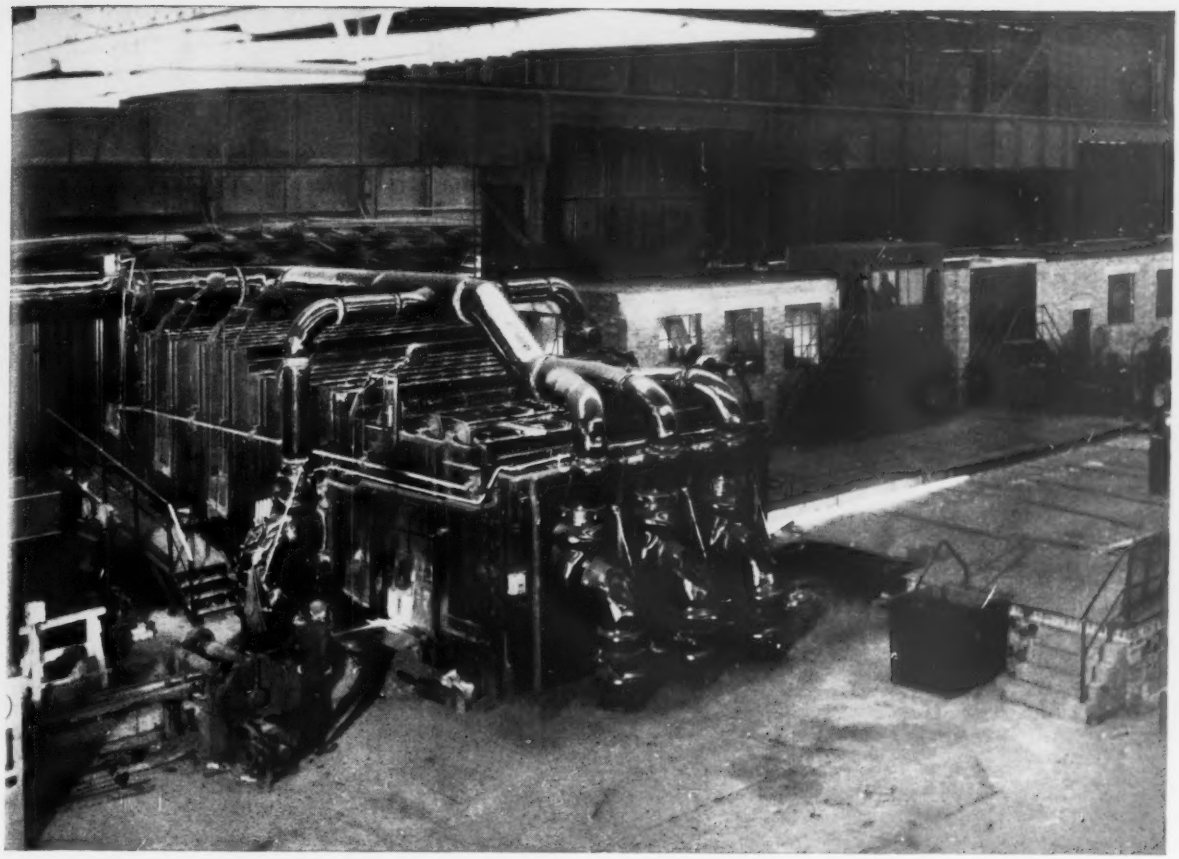

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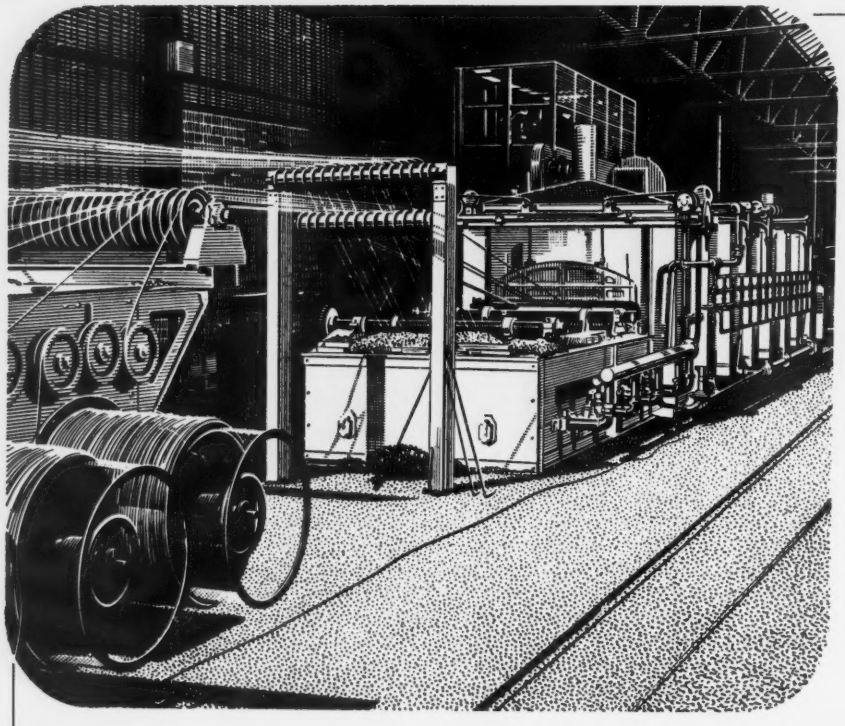

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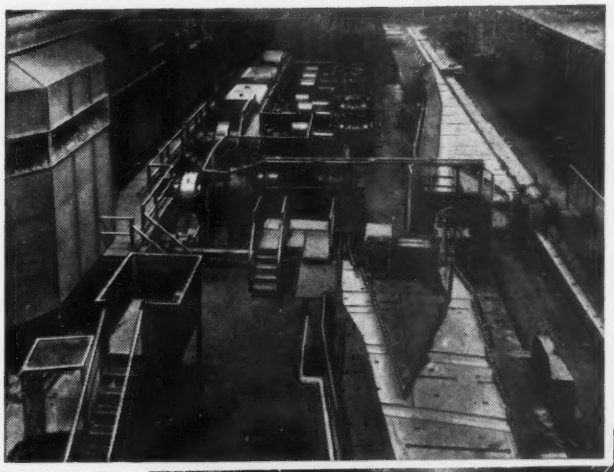

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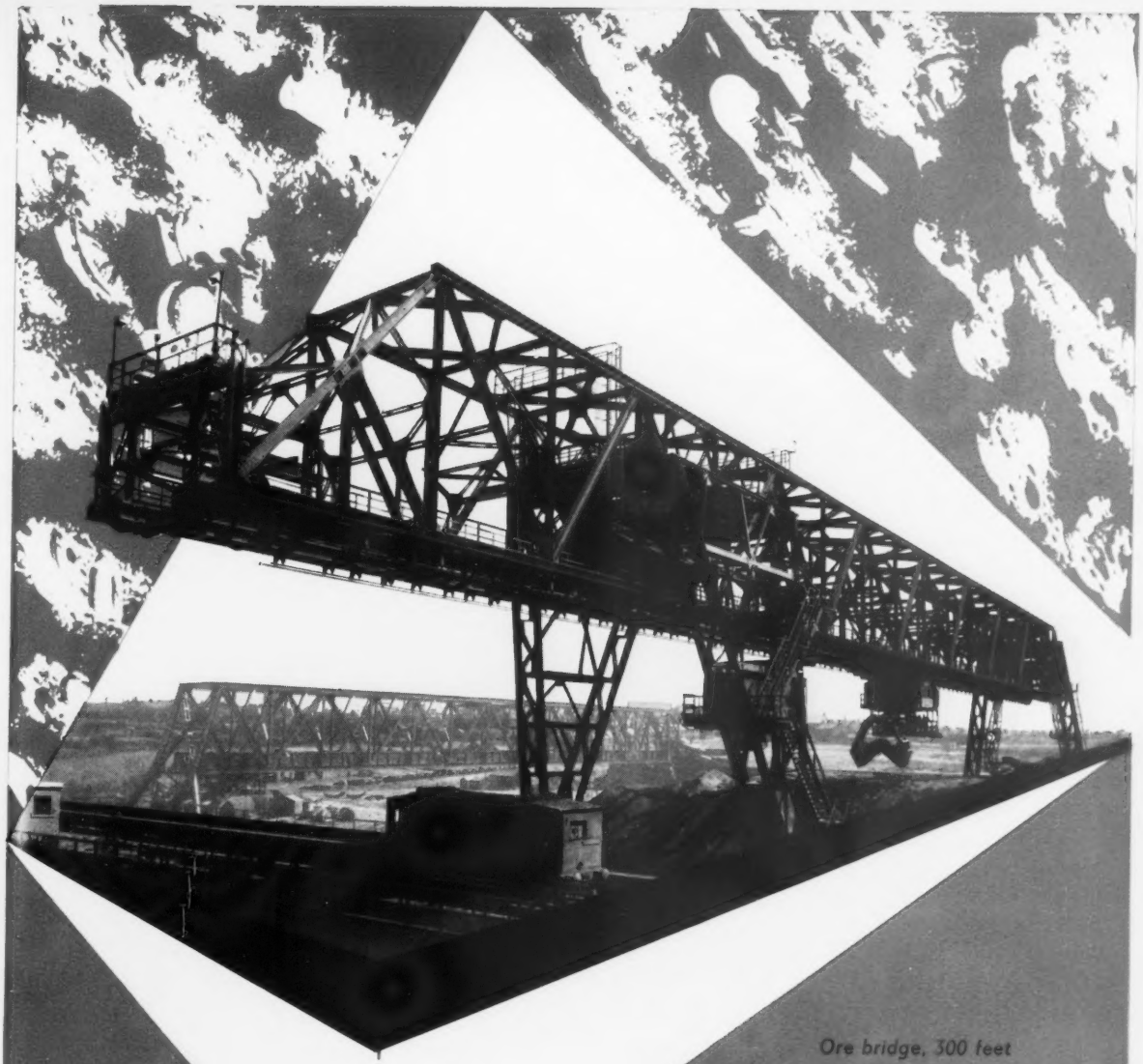

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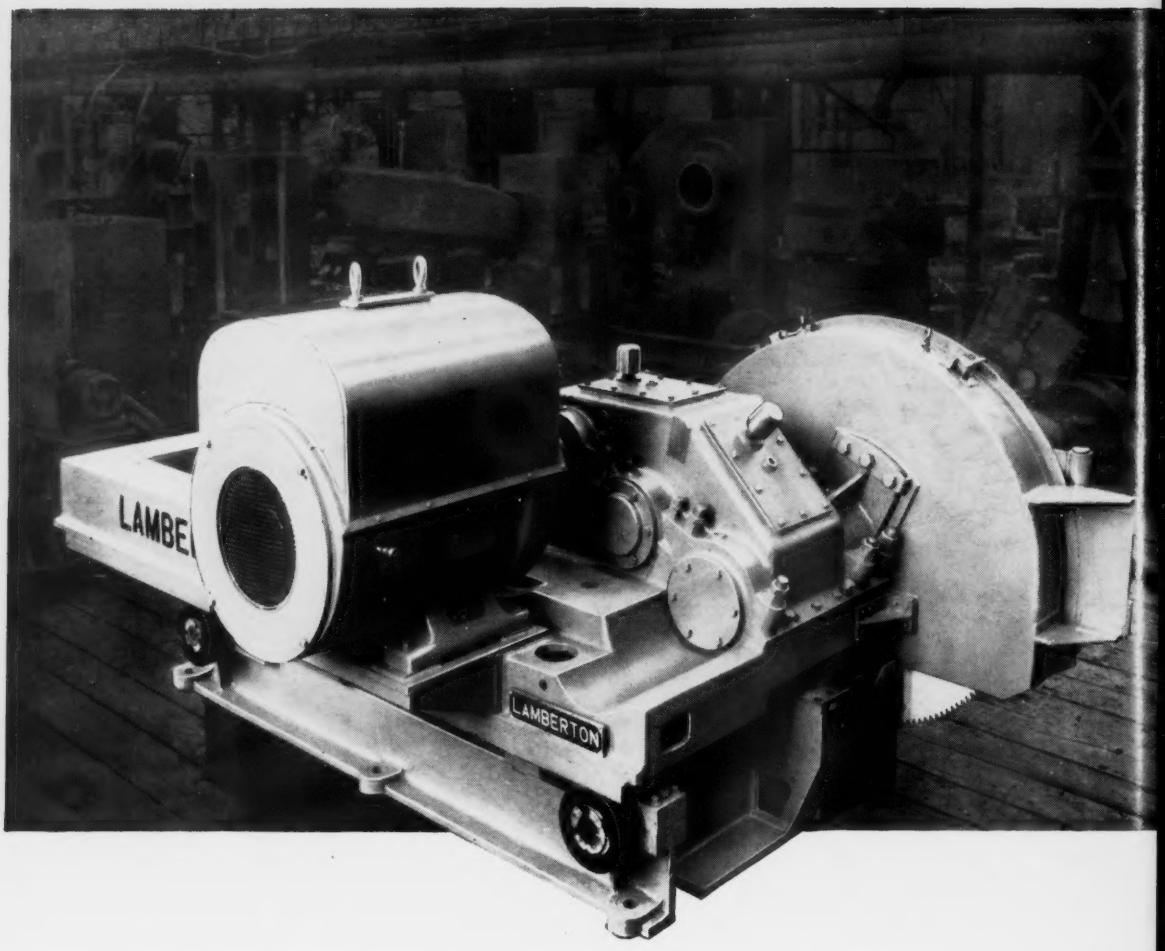

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